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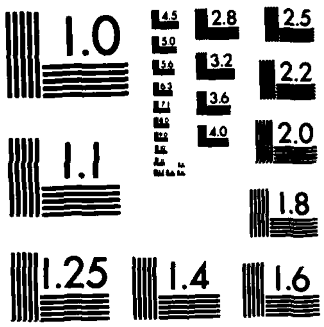

US Army Corps of Engineers
Construction Engineering Research Laboratory

CERL

Technical Report E-193
July 1984
Energy Analysis Methods for Concept Design

AD-A144 684

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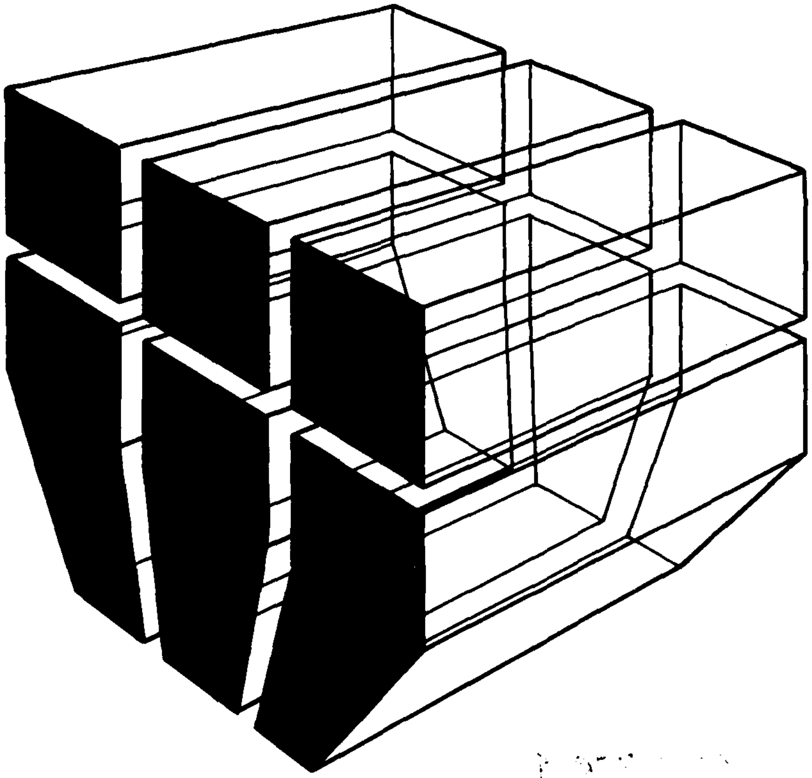
EVALUATION OF MICROCOMPUTER ENERGY ANALYSIS PROGRAMS



by
Linda Lawrie
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This report describes the evaluation of two commercially available microcomputer energy analysis programs to determine their suitability for use at Major Command Headquarters, U.S. Army Corps of Engineers Districts, and Army installations. The evaluation was performed by comparing building simulations provided by micro programs to those provided by the Building Loads Analysis and System Thermodynamics (BLAST) program. The two micro programs chosen for evaluation (OPCOST and SASEAP) are representative of the type of bin method calculations used in simplified energy analysis procedures. (Cont'd)

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The evaluations were based as much as possible on the calculational ability of these programs. No attempt was made to evaluate the ease of use or special features of these programs which might make them more or less suitable to individual users. The major concern was how accurately these programs performed energy calculations. The evaluation was based on four factors: (1) the ability of the programs to calculate overall annual building energy consumption, (2) their ability to study design options for developing energy-efficient new construction, (3) their ability to calculate energy savings from various building retrofit options, and (4) the amount of input information required which would be considered judgmental in nature as opposed to building description oriented.

The results of the evaluation showed that the microcomputer energy analysis programs could reasonably predict the proper ranking of design alternatives or retrofit options. However, the programs could not accurately predict total annual energy consumption. Thus, the micro programs should not be used to determine compliance with energy budgets. Likewise, the micro programs could not predict the actual energy savings due to a design alternative or a retrofit option. The results did not clearly illustrate which design options were modeled accurately.

FOREWORD

This work was performed for the Directorate of Engineering and Construction, Office of the Chief of Engineers (OCE), under Project 4A162781AT45, "Energy and Energy Conservation"; Technical Area A, "New Construction Energy Design"; Work Unit 002, "Energy Analysis Methods for Concept Design." Mr. Edward Zulkofske, DAEN-ECE-E, was the OCE Technical Monitor.

This work was performed by the Energy Systems (ES) Division, U.S. Army Construction Engineering Research Laboratory (CERL). Mr. R. G. Donaghy is Chief of CERL-ES. Appreciation is expressed to Mr. Dale Herron, CERL-ES Division, for his help with the BLAST building energy analyses used in this report, and to Mr. Robert Neathammer of the CERL Facilities Systems Division (FS), for his help with data analysis. A previous study conducted by LT Charles Herring, CERL-FS Division, provided background information.

COL Paul J. Theuer is Commander and Director of CERL, and Dr. L. R. Shaffer is Technical Director.

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EVALUATION OF MICROCOMPUTER ENERGY ANALYSIS PROGRAMS

1 INTRODUCTION

Background

Engineer Technical Letter (ETL) 1110-3-309[1] specifies that an energy analysis be executed on all designs for new Army facilities to insure that they meet the design energy budget. The ETL also requires that the designer "consider all design options and trade-offs in order to minimize energy requirements and life cycle costs." ETL 1110-3-332[2] requires that economic studies be made of all facilities to rank the design alternatives by overall net life-cycle cost (LCC). This ranking includes the impact of the design alternative on the energy consumption portion of the LCC. Thus, an energy analysis of the impact of all the design options is required. In November 1980, the Deputy Chief of Engineers sent a letter to all U.S. Army Corps of Engineers (USACE) Districts, Divisions, and Field Operating Agencies (FOAs) encouraging the use of the Building Loads Analysis and System Thermodynamics (BLAST) computer program for performing the required energy analysis of USACE designs. However, use of this program was not required. Air Force ETL 83-5[3] specifically requires that a computer-based energy analysis be made for all new air-conditioned Air Force facilities larger than 8000 sq ft.

The problem with these requirements is that there are no specifications on how to execute the required energy analysis, particularly regarding energy budget compliance. As a result, a broad range of procedures has been applied to military projects. The question then is whether these procedures are accurate enough for (1) certifying compliance with the prescribed energy budgets, and (2) analyzing the energy impacts of the range of design options being considered for Army and Air Force facilities.

The general consensus in the engineering community is that the detailed energy analysis programs, such as BLAST and DOE 2, are the state of the art in energy analysis and can provide accurate data for design studies over a wide range of design options. Considerable effort has been spent on validating these programs.[4] Other detailed programs such as the Energy Simulation Program (ESP), also are accepted for selected design options, based on the comprehensiveness of their algorithms and field use to date. These programs generally require the use of a mainframe computer system. Their results have been accepted by the Corps of Engineers as accurate enough for design evaluations.

During the last few years a new generation of energy analysis computer programs aimed at microcomputer applications has become available. These programs take a completely different approach to energy analysis. They make significantly greater approximations in solving the heat transfer equations associated with buildings, and greatly simplify the details of the building description used in the energy analysis. However, the impact of these simplifications and approximations on the programs' overall accuracy or on the range of design options which they can be used to study has not yet been completely evaluated.

These microcomputer programs appear to be easier and cheaper to use than the detailed energy analysis programs; as a result, the Corps is getting an increasing number of requests to use them on Corps design projects. However, without clear guidance regarding the programs' accuracy and/or range of applicability, it is difficult to respond to these requests, since selecting the wrong energy analysis method will adversely impact the cost and/or accuracy of a design analysis.

Objective

The objective of this study is to evaluate commercially available microbased energy analysis tools to determine their applicability to various Corps of

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[1] *Interim Energy Budgets for New Facilities*, Engineer Technical Letter (ETL) 1110-3-309 (Office of the Chief of Engineers [OCE], 30 August 1979).

[2] *Economic Studies*, ETL 1110-3-332 (OCE, 22 March 1982)

[3] *Computerized Energy Analyses*, ETL 83-5 (Department of the Air Force, May 1983).

[4] Dale Herron, *Comparison of Building Loads Analysis and System Thermodynamics (BLAST) Computer Program Simulations and Measured Energy Use for Army Buildings*, Technical Report E-174/ADA105162 (U.S. Army Construction Engineering Research Laboratory [CERL], 1981); Brandt Anderson, et al., *Verification of BLAST by Comparison with Measurements of a Solar-Dominated Test Cell and a Thermally Massive Building*, LBL-11387 (Lawrence Berkeley Laboratory, University of California, Energy & Environment Division, April 1981); B. D. Hunn, *The Ultimate in Building Energy Analysis: DOE-2 and BLAST*, DE81 028703 (Los Alamos National Laboratory, 1981); Brandt Anderson, et al., *Verification of BLAST by Comparison with Direct Gain Test Cell Measurements*, LBL-10619 (Lawrence Berkeley Laboratory, University of California, November 1980).

Engineers energy analysis applications in terms of: (1) the calculation of annual energy consumption for energy budget compliance, (2) the study of design options for the development of energy-efficient new construction, (3) the study of energy conservation retrofit options for existing Army facilities, and (4) the amount of input information required which would be judgmental rather than building description oriented.

Approach

Two microprocessor-based energy analysis programs which typify the programs presently available on the commercial market were selected for evaluation. A procedure was developed to evaluate the microcomputer programs' ability to calculate annual energy consumption, evaluate design alternatives for new facilities, and develop retrofit conservation options for existing buildings. The procedure was based on comparisons between the selected programs and BLAST.

The selected microprocessor energy analysis programs were then evaluated to determine the Corps energy analysis uses to which they are applicable. The amount of input required for the microcomputer programs was evaluated, and the ease of obtaining this input was determined in comparison with the more detailed energy analysis programs.

Mode of Technology Transfer

It is recommended that the results of this work be used to update ETL 1110-3-309, *Interim Energy Budgets for New Facilities,* to develop future energy conservation design guidance, and to produce an Engineer Technical Note on the feasibility of installation use of microcomputers for energy analysis.

2 SELECTION OF ENERGY ANALYSIS PROGRAMS FOR EVALUATION

Energy analysis programs use annual weather data to estimate the annual energy consumption of buildings. These programs can be classified according to their use of this data as degree-day, hour-by-hour, or bin methods.

Degree-Day Method

This is the simplest energy analysis method. To calculate building energy consumption, it uses an average daily temperature (usually normalized to a 65°F base) called number of heating or cooling degree days, along with an envelope loss coefficient and an average mechanical system efficiency. Although the method can be used to calculate daily energy consumption, the heating degree days are usually summed over a month or a year to get monthly or annual consumption. The concept of an annual building envelope loss coefficient and an annual seasonal mechanical efficiency is considered valid only for calculating heating energy use for residential construction. Even then, it is considered to be inaccurate for modern homes that use complex controls such as night set-back thermostats and higher-efficiency envelopes, including passive energy homes.

This method is used mostly for projecting energy use of existing buildings from historical energy-use data. Utility companies use this method to estimate utility bills when they cannot get meter readings. Because of its limited scope, this method was eliminated from consideration for this study.

Hourly Energy Analysis Method

This method is based on a transient solution of the time-dependent heat transfer equations governing the energy flows in buildings. This method has two major features: (1) it uses detailed building heat transfer algorithms which use a physical description of the building (such as wall constructions material, descriptions, operating schedules, and actual mechanical equipment specification) as opposed to derived inputs (such as overall envelope heat loss or mechanical system seasonal efficiency); and (2) the transient nature of the solution is preserved, in that the solution starts at one point in time and proceeds chronologically over the time period of interest. The solutions normally use a 1-hour time step and are therefore referred to as hourly energy analysis programs. These procedures also use hourly weather data, including wet- and dry-bulb temperature, wind speed and direction, barometric pressure, and solar radiation obtained from historical weather data.

The hour-by-hour method is not a well-defined procedure. The building heat transfer process is extremely complex; thus, there is a wide selection of algorithms to choose from in implementing this procedure. However, regardless of the actual implementation, the number and complexity of these algorithms and the need to report the calculations for each of the 8760 hours in a year means that this procedure requires a sophisticated computer implementation to be executed properly. There are several computer implementations of this method, including BLAST, DOE, and ESP. Since each of these programs varies in the algorithms used to describe building heat transfer, the accuracy, complexity, ease of use, and cost of these programs also vary.

Although the accuracy and the range of design options that can be evaluated vary among programs, this general approach is considered to be the state of the art in building energy analysis. Unfortunately, microcomputer technology has not progressed to the point where such comprehensive programs can be fully *implemented on these machines.*

Bin Method

This method is a compromise between the heating-degree-day and the hourly procedures. Its name is derived from the fact that the outdoor air temperature is divided into intervals or "bins"; the number of hours when the temperature is in a given "bin" is determined. Heat loss calculations are made for each bin temperature; to get the annual energy consumption, the results are weighted by the number of hours in that bin. The individual bins can be subdivided, depending on building use, to account for night set-back thermostats and for different occupancy/lighting levels. Separate heat loss calculations can then be made for each sub-bin to account for variations in internal building environment. This method also allows the heat loss calculations for each bin to account for the part-load performance of the mechanical equipment. However, the heat loss calculations are still based on the type of simplified envelope heat loss coefficients used in the heating-degree-day method. This is done to keep the procedure a manual method. A drawback of this method is the loss of the transient solution of heat transfer process, since the hourly (bin) calculations do not account for the state of the building during the previous hours.

The first practical implementation of this method was the Rational Energy Analysis Program (REAP) developed by the Carrier Corporation. The procedure has had various implementations, with the most recent being the Simplified Energy Analysis Program developed by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE). Although these bin methods are intended to be manual, it can be extremely tedious to carry them out in detail. Thus, several microcomputer implementations have been developed. One advantage of such an implementation is that the computer can greatly enhance the user's ability to make the heat loss calculations. It can calculate the heat loss coefficients based on building-related inputs, such as a window area, U-values, thermostat settings, etc. The major variations among the different programs are the detail and comprehensiveness used to calculate the heat loss coefficients.

Most microcomputer energy analysis programs are based on the bin method; therefore, two representative programs based on this method were chosen for evaluation in this study. The first is the Carrier Corporation OPCOST Version 1.5 program.[5] This was one of the first microcomputer programs which was widely marketed to the architect/engineer (A/E) community and is the one which may be used for energy analysis on Corps projects. The second program chosen was the Sud Associates Simplified Energy Analysis Program Version 1.2 (SASEAP).[6] This program was chosen because it was an implementation of the ASHRAE Simplified Energy Analysis Program and is also readily available to the A/E community. The selection of these two programs in no way indicates that these are the best microenergy analysis programs, but only that they are typical of this type of program and are available to the engineering community.

Since this study began, other microcomputer energy programs have become available. Lack of time [illegible]vented evaluation of all of them; also, the propr[illegible]y nature of these programs precludes a technical e[illegible]tion of their algorithms. However, the results g[illegible] in this report, based on the analysis of the two s[illegible] programs, are felt to be typical of most current e[illegible] analysis programs based on the bin method and of the bin method itself. An evaluation of the special features of these programs, which might make a particular program easier to use, was not made. The following sections briefly describe the programs selected for evaluation.

Carrier OPCOST Program

OPCOST is one of Carrier's family of E20-II programs; other programs are Load Estimating, Duct Design, and Equipment Selection. OPCOST uses the Carrier Modified Bin Method to calculate heating and cooling loads for any size building, models the system and plant energy use, calculates annual energy consumption in Btus and by fuel type, and also calculates total dollar operating cost, including lights and auxiliaries. It is a totally interactive, multi-optioned, design/analysis tool that prompts the user with questions and presents menus of alternatives for output, building, and system description.

Weather data are supplied for 329 cities, and the user may also enter preferred climatological data.

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[5] *Operating Cost Analysis Version 1.5 (OPCOST) User's Manual* (Carrier Corporation, 1981).

[6] *Sud Associates Simplified Energy Analysis Program (SASEAP) User's Manual* (Ish Sud Associates, December 1980).

Weather data consist of temperature bin data, humidity ratio, and ASHRAE solar data. ASHRAE summer and winter design conditions are also included.

The building load is calculated based on envelope areas, thermal properties of components, internal loads, operating schedules, ventilation and infiltration. The program offers many outputs, including a printout of all inputs, weather data, bin loads, occupied and unoccupied loads, perimeter loads, interior loads, and total heating and cooling loads; all of these outputs may be graphed.

Once the load calculation is completed, the system and plant are described to the program. The annual operating cost in dollars for perimeter, interior, occupied and unoccupied, and total is displayed and may be printed. The energy budget can be computed and the total cost and amount of energy consumption by fuel type, including lights and miscellaneous, is printed out. The building description is stored, and OPCOST may be run again with any retrofits desired.[7]

Sud Associates Simplified Energy Analysis Program (SASEAP)

SASEAP is based on the modified bin procedure developed by Technical Committee (TC) 4.7 of ASHRAE. The input is a single 8½- by 11-in. input data form that the user enters on the computer line by line. This establishes a building data file on the same disk as the program. As an alternative, all the files may be stored on a separate disk. A disk can hold up to 75 building or weather files.

SASEAP supplies 33 weather files on the program disk; it also has programs that allow the user to create weather files of preferred data. Weather files consist of frequency of occurrence of bin hours of temperature data, humidity ratio, and ASHRAE solar data. The output is a single page and gives the total design loads, bin temperature-load profile for occupied and unoccupied periods, and annual energy consumption of building components, such as total annual energy usage by fuel type. SASEAP can be used for estimating the design heating and cooling loads, obtaining a load profile under given operating conditions, estimating annual energy requirements, and analyzing buildings for retrofit options.

After each run, the program prompts the user for changes in the data set to evaluate the next alternative. The user may examine the results of the previous alternative and make appropriate changes to resubmit the run, or evaluate a new alternative. The user can also store the building data for further analysis later. At present, the program can analyze only nonreheat-type HVAC systems, since it equates space loads to equipment loads.[8]

3 EVALUATION METHODOLOGY AND CRITERIA

The best method for evaluating these microcomputer energy analysis programs would be to compare their results with experimental data. However, such data were not available over the full range of building types and design options. Therefore, the method chosen was to compare the program results with these obtained from detailed (hourly) energy analysis programs. The reference detailed program chosen was the Army's BLAST program.[9] Considerable effort has been spent to validate this program,[10] and there is general consensus that it is a leader in the detailed energy analysis field.

The approach to creating each program's input model attempted to emulate what a designer might actually do if he/she had access to only one energy analysis program. The Kusuda article illustrates the differences which may occur when various designers model the same building.[11] Thus, the input models were carefully reviewed to assure the same assumptions about the building (e.g., outside air, construction

[7] *Operating Cost Analysis Version 1.5 (OPCOST) User's Manual*

[8] *Sud Associates Simplified Energy Analysis (SASEAP) User's Manual.*

[9] D. C. Hittle, *The Building Loads Analysis and System Thermodynamics (BLAST) Program, Version 2.0 Volumes I and II*, Technical Report E-153/ADA072272 and ADA072273 (CERL, 1979); D. Herron, *Building Loads Analysis and System Thermodynamics (BLAST) Program User's Manual Volume I, Supplement*, Technical Report E-171/ADA099054 (CERL, 1981).

[10] *Comparison of Building Loads Analysis and System Thermodynamics (BLAST) Computer Simulations and Measured Energy Use for Army Buildings; Verification of BLAST by Comparison with Measurements of a Solar Dominated Test Cell and a Thermally Massive Building, The Ultimate in Building Energy Analysis: DOE-2 and BLAST; Verification of BLAST by Comparison with Direct Gain Test Cell Measurements.*

[11] T. Kusuda, "A Comparison of Energy Calculation Procedures," *ASHRAE Journal* (August 1981).

types, and other factors). Each input model was created based on the inputs required by that individual program.

Two kinds of evaluations were performed. The first analyzed only building design options which the micro programs could simulate. Microcomputer programs make simplifying assumptions about the buildings being simulated that restrict the options that can be evaluated. For example, neither OPCOST nor SASEAP can account for nonrectangular-shaped zones, nonrectangular surfaces, or external shading. (Other differences between the simulation capabilities of simplified microcomputer programs and BLAST are discussed in Chapter 4.) Thus, the first evaluations did not use any building design features which the microcomputer programs could not simulate. In addition, the weather bin data used with OPCOST and SASEAP were derived from the weather data tapes used by BLAST.

The first evaluation included two studies: (1) an examination of a building being formed component by component (box study), and (2) a retrofit study using the first study's building (box retrofit).

The second evaluation included: (1) the impact of using vendor-supplied weather data instead of the data generated for the actual sites, and (2) studied the impact of design options which the micro programs could not readily simulate. In the first case, simulations of the most energy-efficient retrofit options from the first study were repeated using vendor-supplied weather data. Next, comparisons were done for a building design which included features not available in the microcomputer programs; this would determine the potential magnitude of error if the micro programs are used for these buildings and these design options are ignored.

Evaluation 1 (Box Study)

A stepwise approach to modeling a complete building was used to quantify the ability of the various programs to simulate the effects of individual building components on energy consumption. The baseline structure was a simple 6720-sq-ft structure with four opaque walls and a roof. Each additional case added a building component until a complete building was analyzed. Figure 1 shows these six cases and the components added for each step.

Besides studying the ability of the individual programs to evaluate the effects of various building components, this investigation also determined the ability of these programs to predict annual energy consumption—a factor needed to check for budget compliance.

Case 1: Simple Box, Opaque Walls, Roof

Case 2: Add Slab Floor

Case 3: Add Glazing on the South Side of Building

Case 4: Add Glazing on the Other Three Sides of Building

Case 5: Add Ventilation/Infiltration

Case 6: Add Internal Loads (People. Lights)

Figure 1. Box study.

Evaluation 1 (Box Retrofit)

The first retrofit study was based on the building created in the box study. Six retrofit options were analyzed using Case 6 of the box study as the baseline. Figure 2 lists the options.

Evaluation 2

The first part of this evaluation simulated cases A and G of the box retrofit study, using the vendor-supplied weather data for OPCOST and SASEAP instead of the bin data derived from the BLAST weather data. This step might be taken by a designer as a quick approach (i.e., not wanting to make the required weather data). Choosing to use vendor-supplied weather data can have some interesting results as described later. OPCOST studies were done for Phoenix, AZ, Bismark, ND, and Columbia, MO. SASEAP studies were done for Phoenix, AZ, Bristol, TN (replacing Columbia, MO), and Minneapolis, MN (replacing Bismarck, ND). Where supplied locations did not match the chosen locations, the replacement locations were chosen based on similarity of heating and cooling design temperatures.

Case A: Same as Case 6

Case B: Reduction of Ventilation/Infiltration

Case C: Addition of Storm Windows

Case D: Addition of Insulation in Walls and Ceiling

Case E: Reduction of Window Area

Case F: Addition of Night Set-Back Thermostat

Case G: Cumulative, Case B Through Case F

Figure 2. Box retrofit.

The second part of this evaluation added more complex building design features to Case D of the box retrofit study. Overhangs, which neither microcomputer program can simulate, were added, and the amount of south-facing glass was increased to 50 percent. A night and weekend set-back thermostat was also simulated. New models were prepared for each program (only the BLAST model had overhangs).

Evaluation Methodology

The evaluations for each study tried to answer the following questions:

1. Were the actual energy consumption predictions which would be used for design energy budget comparisons accurate (when compared with BLAST)? The answer is found by comparing the microcomputer and the BLAST results on a case-by-case basis. For example, the OPCOST results of Case 1 for Phoenix were compared with the BLAST results of Case 1 for Phoenix.

2. Did the results accurately predict the correct energy savings of a retrofit option? This is answered by comparing a particular option's results with the baseline case results and then comparing the difference (baseline minus retrofit option) with the difference for BLAST. For example, the SASEAP net energy savings for adding storm windows (Case C) in Columbia was compared with the BLAST net energy savings for this case and location.

3. Did the programs accurate predict the correct ranking of retrofit options? This question is answered by ranking the net energy savings predicted by the micro programs of each retrofit option and comparing this ranking with BLAST's ranking. For example, the savings of Case B through Case G were ranked by net energy savings and the case ranking compared with BLAST's ranking.

Once the simulations were complete, the results were analyzed. First, the results were viewed manually to get an intuitive feel for differences. Then percentage differences were calculated against the "standard" (either the BLAST results or the baseline case of the program), and statistical analyses (analysis of variance, for example) were performed to determine the extent of agreement/disagreement among the programs.

Annual Energy Comparison

The results of each of the runs were tabulated to show total energy consumption, heating load, and cooling load. For BLAST, each amount is obtained from the SYSTEM LOADS report (Figure 3). Heating and cooling are the Total Heating/Cooling Provided by the System figures. Total energy consumption is the total heating/cooling consumption plus the total building electrical consumption. For OPCOST, each amount is obtained from the Energy Budget Summary report (Figure 4). Heating and cooling are the Remote Heating/Cooling figures. Total energy consumption is obtained from the Grand Total line. In each case, the column titled DOE RIF is used. For SASEAP, each amount is obtained from the Loads and Energy Requirements Per Sq Ft of Building Area report (Figure 5). Heating and cooling are the Building Loads, BTU/SQ. FT-YR line multiplied by building area. Heating per square foot is the sum of Occupied Heating and Unoccupied Heating. Total energy consumption is obtained from the untitled Totals line multiplied by building area. The percent deviation from BLAST was then calculated, and an analysis of variance was performed on these results to determine which factors have a statistically valid effect on the outcome of the energy analysis. The purpose of the analysis was to determine statistically whether the locations, the cases, or the microcomputer program used affect the percentage of deviations found in energy consumption. Original expectations were that, although answers across locations would differ, the percentage of deviations should be more or less constant for a given option in a microcomputer program. It was also thought that the maximum percentage of deviations from BLAST would be about 15 to 20 percent. Thus, if BLAST predicted a 20 percent savings, the expected micro program predictions could reasonably range from 5 to 35 percent.

Net Savings Comparison

The results of total energy consumption, heating load, and cooling load were used to compare net energy savings. For the box study, Case 1 was used as the baseline for each program, and differences and percentage differences were tabulated for Cases 2 through 6. Thus, for Study 1, the net savings comparison can be loosely interpreted as the effect of a particular design variable (e.g., glazing, floor heat transfer). For the box retrofit, Case A was used as the baseline for each program, and differences and percentage differences were tabulated for Cases B through G. Thus, for the box retrofit study, the net savings comparison can be interpreted as the effect of using a particular retrofit option.

Ranking Comparison

Within each study, the cases were ranked according to predicted energy consumption and the results were

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US ARMY CORPS OF ENGINEERS -- BLAST VERSION 3.0  LEVEL  85*

**************************************************************************
**                                                                      **
**   A I R   H A N D L I N G   S Y S T E M   L O A D   S U M M A R Y    **
**                                                                      **
**************************************************************************

  SYSTEM 1                                          SYSTEM NUMBER =          1

  SYSTEM LOCATION =  13983     SIMULATION PERIOD =  1/ 1/1968 - 12/31/1968

                                   TOTAL DEMAND       PEAK DEMAND      TIME OF PEAK
                                      (BTU)            (BTU/HR)         MO/DY/HR

SUM OF ZONE SENSIBLE
HEATING LOADS                      1.34868E+08        1.05551E+05        1/ 7/ 8

TOTAL HEATING PROVIDED
BY SYSTEM                          4.84680E+08        3.29841E+05        1/ 7/ 8


SUM OF ZONE SENSIBLE
COOLING LOADS                      7.54970E+07        6.50358E+04        8/ 6/17

SENSIBLE COOLING
PROVIDED BY SYSTEM                 7.94155E+07        1.12597E+05        8/23/16

LATENT COOLING
PROVIDED BY SYSTEM                 5.84609E+07        1.45543E+05        8/ 8/17

TOTAL COOLING PROVIDED
BY SYSTEM                          1.37876E+08        2.38380E+05        8/ 6/17



TOTAL ENERGY CONSUMED BY SYSTEM AND ZONES =  6.91461E+08

TOTAL FLOOR AREA SERVED BY FAN SYSTEM =         6.72000E+03   FT**2


ENERGY BUDGET  (TOTAL ENERGY/FLOOR AREA) =      1.02896E+05 BTU/FT**2

NOTE: THIS ENERGY BUDGET DOES NOT INCLUDE ANY LOADS NOT MET
OR ANY ENERGY FOR DOMESTIC HOT WATER.  IT ALSO DOES NOT
INCLUDE THE EFFECT OF THE PLANT ON ENERGY CONSUMPTION.
```

Figure 3. System Loads report from BLAST.

ENERGY BUDGET SUMMARY

REMARKS: COL BOX W/ INTERNAL LOADS

HVAC ENERGY	ANNUAL $	# FUEL UNITS	UNITS	DOE RUF MBTU'S	DOE RIF MBTU'S
ELECTRIC (OCC)	$311.14	5185.7	KWH	60154	17694
ELECTRIC (UNOCC)	$0.00	0.0	KWH	0	0
NATURAL GAS	$0.00	0.0	THERMS	0	0
OIL	$0.00	0.0	GAL	0	0
PROPANE	$0.00	0.0	LBS	0	0
REMOTE HEATING	$9044.13	602.9	MILL. BTU	602942	602942
REMOTE COOLING	$3271.58	218.1	MILL. BTU	218106	218106
HVAC SUBTOTAL	$12626.86		ALL	881202	838742

OTHER ENERGY	ANNUAL $	# FUEL UNITS	UNITS	DOE RUF MBTU'S	DOE RIF MBTU'S
ELECTRIC (OCC)	$777.08	12951.3	KWH	150235	44190
ELECTRIC (UNOCC)	$0.00	0.0	KWH	0	0
NATURAL GAS	$0.00	0.0	THERMS	0	0
OIL	$0.00	0.0	GAL	0	0
PROPANE	$0.00	0.0	LBS	0	0
REMOTE HEATING	$0.00	0.0	MILL. BTU	0	0
OTHER SUBTOTAL	$777.08		ALL	150235	44190
GRAND TOTAL	$13403.94		ALL	1031437	882931
(PER SQ.FT.)	$1.99		DOE MBTU/GSF	153	131

```
1 KWH    = 11600 BTU'S(RUF), 3412 BTU'S(RIF)
1 THERM  = 100000 BTU'S (RUF OR RIF)
1 GAL    = 138700 BTU'S (RUF OR RIF) (FUEL OIL)
1 LB PRO= 21680 BTU'S (RUF OR RIF)
RIF      = RESOURCE IMPACT FACTOR (POINT OF USE VALUE)
RUF      = RESOURCE UTILIZATION FACTOR (SOURCE VALUE)
HVAC     =   1.88 $/GSF
         =  94.20 %TOT.$
         =   0.77 KWH/GSF/YR
         =  28.59 %TOT.KWH
         = 100.00 %NON-ELEC.ENERGY

INPUTS : OTHER ELECTRIC KW/HR (OCC./UNOCC.) =     0.0/    0.0
         SANITARY HOT WATER FROM ELEC. HEATER RATED @  1   GAL/HR. RECOVERY
         GPH HW USAGE (OCC./UNOCC.) =  0 / 0  @  120 F. FROM  61.9215 F.
         $/KWH (OCC/UNOCC) = $0.060 / $-.000
         $/MILL.BTU'S       = $ 15   (HTG.)
         $/MILL.BTU'S       = $ 15   (CLG.)
```

Figure 4. Budget Summary report from OPCOST.

SUD ASSOCIATES SIMPLIFIED ENERGY ANALYSIS PROGRAM
BUILDING ENERGY ANALYSIS PERFORMED BY SUD ASSOCIATES, P.A.

BOX BUILD UP   OPTION NO. 1 COL BOX INTERNAL LOAD
AREA = 6720

BLOCK SOLAR LOAD,BTUH/SF MAX 7.4 DIV SUMMER 3.2 DIV WINTER 2.3

TRANSMISSION LOADS,BTUH/SF MAX SUMMER 9.3 MAX WINTER -27.9
DIV OCCUP: 97.5, 7.0 ; 77.5, 0.8 ; 57.5, -1.8 ;-12.5,-27.0
DIV UNOCC: 57.5, 2.7 ;-12.5,-22.5

LOADS AND ENERGY REQUIREMENTS PER SQ FT OF BUILDING AREA

N	T	OCCUPIED COOLING FREQ	OCCUPIED COOLING LOAD(BTUH) SENS	OCCUPIED COOLING LOAD(BTUH) TOT	OCCUPIED COOLING INPUT BTUH	OCCUPIED COOLING INPUT BTU	OCCUPIED HEATING LOAD BTUH	OCCUPIED HEATING INPUT BTUH	OCCUPIED HEATING INPUT BTU	UNOCCUPIED HEATING FREQ	UNOCCUPIED HEATING LOAD BTUH	UNOCCUPIED HEATING INPUT BTUH	UNOCCUPIED HEATING INPUT BTU
1	97.5	1	21.0	39.2	39.2	39	0.0	0.0	0	0	0.0	0.0	0
2	92.5	116	17.2	35.5	35.5	4113	0.0	0.0	0	0	0.0	0.0	0
3	87.5	306	13.4	28.2	28.2	8628	0.0	0.0	0	0	0.0	0.0	0
4	82.5	457	9.6	23.1	23.1	10543	0.0	0.0	0	0	0.0	0.0	0
5	77.5	710	5.9	17.8	17.8	12603	0.0	0.0	0	0	0.0	0.0	0
6	72.5	788	4.1	13.0	13.0	10245	0.0	0.0	0	0	0.0	0.0	0
7	67.5	832	2.3	8.3	8.3	6865	0.0	0.0	0	0	0.0	0.0	0
8	62.5	780	0.5	3.5	3.5	2732	0.0	0.0	0	0	0.0	0.0	0
9	57.5	770	0.0	0.0	0.0	0	1.2	1.2	960	0	0.0	0.0	0
10	52.5	595	0.0	0.0	0.0	0	5.3	5.3	3134	0	0.0	0.0	0
11	47.5	500	0.0	0.0	0.0	0	9.3	9.3	4643	0	1.4	1.4	0
12	42.5	547	0.0	0.0	0.0	0	13.3	13.3	7279	0	5.4	5.4	0
13	37.5	545	0.0	0.0	0.0	0	17.3	17.3	9443	0	9.4	9.4	0
14	32.5	493	0.0	0.0	0.0	0	21.3	21.3	10523	0	13.4	13.4	0
15	27.5	463	0.0	0.0	0.0	0	25.4	25.4	11744	0	17.5	17.5	0
16	22.5	332	0.0	0.0	0.0	0	29.4	29.4	9756	0	21.5	21.5	0
17	17.5	239	0.0	0.0	0.0	0	33.4	33.4	7984	0	25.5	25.5	0
18	12.5	157	0.0	0.0	0.0	0	37.4	37.4	5876	0	29.5	29.5	0
19	7.5	90	0.0	0.0	0.0	0	41.4	41.4	3730	0	33.5	33.5	0
20	2.5	29	0.0	0.0	0.0	0	45.5	45.5	1318	0	37.6	37.6	0
21	-2.5	20	0.0	0.0	0.0	0	49.5	49.5	990	0	41.6	41.6	0
22	-7.5	10	0.0	0.0	0.0	0	53.5	53.5	535	0	45.6	45.6	0
23	-12.5	4	0.0	0.0	0.0	0	57.5	57.5	230	0	49.6	49.6	0

INDICATED DESIGN CAPACITIES, BTUH: COOLING 264844 ; HEATING-336360
ANTICIPATED SUMMER PEAK : 12.12 W/SF 81.4 KW

ANNUAL ENERGY USAGE	PER SF	TOTAL	EQUIV FULL HRS
LIGHTING	1.9 KWH	12957 KWH	
INTERNAL EQUIPMENT	0.0 KWH	0 KWH	
COOLING EQUIPMENT	16.3 KWH	109803 KWH	468
HEATING EQUIPMENT	0.8 CCF	5251 CCF	656
FANS & AUXILARIES	1.1 KWH	7379 KWH	

TOTALS

ELECTRICITY	130138 KWH	66096	BTU/SQ.FT-YR
NAT GAS	5251 CCF	78145	BTU/SQ.FT-YR
		144241	BTU/SQ.FT-YR

BREAKDOWN OF SYSTEM OPERATION AND ENERGY USAGE/SF

	OCCUPIED COOLING	OCCUPIED HEATING	UNOCCUPIED HEATING
SYSTEM HOURS	3990	4794	0
BUILDING LOADS,BTU/SF-YR	55768	78145	0
COOLING EQUIPMENT,KWH/SF	16.3		
HEATING EQUIPMENT,CCF /SF		0.781	0
FANS AND AUXILARIES,KWH/SF	0.5	0.6	0.0

Figure 5. Loads and Energy Requirements per sq ft Report from SASEAP.

tabulated for each study in each location. Comparisons were then made to determine how well the micro results agreed with those of BLAST.

4 MICROCOMPUTER ENERGY ANALYSIS PROGRAM EVALUATION RESULTS

Evaluation 1

Weather File Information

To insure that all programs were using the same weather information, the bin temperature data required for both OPCOST and SASEAP were taken from the weather data used for the BLAST runs. Both OPCOST and SASEAP required some information about the average percentage of sunshine and the solar heat gain factors (SHGF). SASEAP required winter and summer averages for the percentage of sunshine, and winter and summer averages for SHGF for all orientations. OPCOST required monthly averages for the percentage of sunshine and SHGF for all orientations. The SHGF information was obtained from ASHRAE's *Handbook of Fundamentals*,[12] while the percentage of sunshine data were obtained from the National Oceanic and Atmospheric Administration's (NOAA) *Climates of the States*.[13] The SHGF information is given for different latitudes, while the sunshine information is given for each city.

The temperature bins are divided into 5-degree segments for each location. SASEAP's weather data permits up to 25 temperature bins at any degree interval, while OPCOST permits only 24 temperature bins at 5-degree intervals. The Bismarck weather data had a temperature range covering 28 temperature bins, so the weather data was compacted into 24 bins. Since only 28 hours of the 8760 total hours were affected by this composition, simplification is not considered significant (these 28 hours represent 0.3 percent of the year). The other two locations used are exact duplicates of the temperature data from the BLAST weather tapes.

Box Study

The baseline model (Case 1) for this analysis was a 6720-sq-ft building with 7968 sq ft of opaque wall area and 6720 sq ft of roof/ceiling area. The U-value of the four walls was 0.138, and the U-value of the roof was 0.047. The indoor temperatures were set at 68°F for heating and 78°F for cooling. A single-zone, draw-through fan system provided the heating and cooling.

Case 2 added a floor to account for the heat transfer through the slab on grade. Both micro programs modeled approximately the slab-on-grade floor. SASEAP had an input for additional heat loss per square foot, so an average yearly heat loss from the floor was approximated. (A simple conduction equation was used to estimate the average heat transfer through the floor. The parameters used for this calculation were the thermal properties of the floor, the area of the floor, a yearly average of the interior design temperature, and the yearly average ground temperature under the building.) OPCOST had an input labeled "square feet adjacent to non-design temperatures," and another input for the temperature of the uncooled/unheated space in both the heating and cooling seasons; these were used to calculate the heat loss/gain through the floor. (Two simple conduction equations were used to approximate the heat transfer through the floor. The parameters used for these calculations were the thermal properties of the floor, the area of the floor, a summer average interior design temperature, a winter average interior design temperature, a summer average ground temperature, and a winter average ground temperature.)

Case 3 added glazing to the south side of the building. About 15 percent of the south wall area (360 sq ft of the 2304 sq ft of wall) was changed to ¼-in., single-pane glass.

Case 4 added glazing on the remaining three sides. About 10 percent of the wall area of the remaining three sides was changed to ¼-in., single-pane glass. On the east and west sides, 170 sq ft of the 1680 sq ft on each side were changed to glass. On the north side of the building, 230 sq ft of the 2304 sq ft were changed to glass.

Case 5 introduced outside air into the building. The typical fresh air requirement for living/office space is one air change per hour.[14] The two typical methods of introducing outside air are ventilation and/or infiltration. SASEAP's input allowed only for the greater of the two air exchange methods,[15] while OPCOST's

[12] *Fundamentals Handbook and Product Directory* (American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 1977).

[13] *NOAA Climates of the States* (Gale Research Company, 1978).

[14] *Fundamentals Handbook and Product Directory*.

[15] *Sud Associates Simplified Energy Analysis Program (SASEAP) User's Manual*.

input allowed for both ventilation and infiltration. For consistency, the inputs to both SASEAP and OPCOST were assumed to be one air change of ventilation per hour (2688 cu ft/min).

Case 6 added internal loads, which include lighting, equipment, and people. The lighting and occupancy schedules and quantities were determined by assuming that this facility would have the same lighting and occupancy as a dormitory (this schedule was taken directly out of the BLAST library). The quantities calculated were an average occupany of 41 people (.006 per square foot)[16] and an average electrical load (lighting) of 1.5 kW (.22 w/sq ft).[17] OPCOST's input takes an average value for both the occupied and the unoccupied periods. SASEAP's input allows for a peak load and a fractional use for the occupied and the unoccupied periods, both for occupancy and lighting loads.

Input models for BLAST, OPCOST, and SASEAP were prepared for each of these cases, and each case was simulated by each program in three locations: Phoenix, AZ, Columbia, MO, and Bismarck, ND. The results available from each simulation included the total annual energy consumption of the building and its annual heating and cooling requirements.* Table 1 shows simulation results.

To compare the annual energy consumption predictions of the micro programs with BLAST's predictions, the percentage differences between the micro programs and BLAST predictions were computed for each case (see Table 2). An analysis of variance was then performed using the percent differences; Figure 6 shows the results graphically. These results indicate that there are substantial differences between the predictions given by the micro programs and by BLAST. For example, the total annual energy consumption predictions of the micro programs deviated from BLAST's by up to 40 percent. The analysis of variance indicated that for total energy consumption, the differences between the micro predictions and the BLAST predictions depend greatly on the location and the combined effect of both location and computer program. For heating and cooling consumption, the analysis of variance indicated that the differences are a strong function of the computer program selected and the location. The analysis of variance on these data indicates that there is no consistent trend which would relate the micro program's prediction to BLAST's. Thus, the use of the micro programs to perform an energy analysis of the building used in the box study could cause significant errors in the predicted annual energy consumption.

To determine the effect of each design variable on the energy consumption predicted by each program, the change in predicted energy consumption between successive cases was computed (see Table 3). For example, the difference between the total energy consumption prediction for Case 1 and Case 2 is an indication of the effect of the addition of the slab-on-grade floor on the building's energy consumption. Table 3 shows that the results of the micro programs are highly variable according to the design variable added to the simulation model. For example, in Case 2, the range of deviation for all locations from BLAST's percentage differences are well within the 15 to 20 percent guideline chosen originally. However, Case 5 (the addition of infiltration/ventilation) illustrates variations from BLAST's percentage differences that range from 4 to 300 percent for all locations.

Box Retrofit

Case A the baseline for this study is the same as Case 6 in the box study (i.e., a complete building with internal loads, infiltration/ventilation, and windows).

Case B reduced the infiltration/ventilation of Case A from one air change per hour to three-quarters of an air change per hour (2688 cu ft/min to 2016 cu ft/min).

Case C added storm windows to Case A. this added a 1/8-in. sheet of glass and an air space to the 1/4-in pane of glass that was already in place. This changed the U-value of the window from 1.115 to 0.556.

Case D added insulation to the walls and the ceiling of Case A. The U-value in the walls was lowered from 0.138 to 0.069, while the U-value of the ceiling was lowered from 0.048 to 0.024.

Case E reduced the window area of Case A. A 50 percent reduction was used for this study, thus lowering the window area to 180 sq ft for the south side, 115 sq ft for the north side, and 85 sq ft for the east and west sides.

[16] *Fundamentals Handbook and Product Directory*

[17] *IES Lighting Handbook* (Illuminating Engineering Society, 1981)

*Total energy consumption includes the electricity demands of the lights and equipment within the building, as well as the electricity, hot water, and chilled water demands of the fan system.

Table 1
Box Study Annual Energy Consumption (Million Btu)

	TOTAL ENERGY CONSUMPTION			HEATING CONSUMPTION			COOLING CONSUMPTION		
PHOENIX	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE 1	140.5	136.1	151.6	20.6	50.3	44.9	100.1	79.1	81.6
CASE 2	132.1	121.2	148.7	24.1	45.1	45.5	81.3	71.3	78.1
CASE 3	170.8	168.3	202.6	6.4	35.8	23.6	148.1	125.8	153.8
CASE 4	247.5	281.0	320.2	8.6	42.5	20.1	222.1	205.0	275.0
CASE 5	466.5	620.5	515.7	74.9	193.9	142.8	369.0	406.7	347.8
CASE 6	573.5	708.1	633.8	54.9	145.4	101.7	450.1	496.0	462.9
COLUMBIA	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE 1	177.8	199.6	218.0	139.5	177.8	168.6	19.3	19.4	24.3
CASE 2	180.1	208.9	216.4	167.5	197.3	170.2	5.8	9.3	21.0
CASE 3	193.0	217.5	240.5	152.9	190.8	167.5	22.4	24.4	47.9
CASE 4	247.8	291.1	319.4	183.0	241.1	193.5	47.1	46.1	100.7
CASE 5	672.7	868.6	914.6	561.8	678.6	598.6	87.3	172.4	290.7
CASE 6	691.5	882.9	969.3	484.7	602.9	525.1	137.9	218.1	374.8
BISMARCK	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE 1	297.2	337.9	350.9	272.1	325.6	310.1	5.4	10.9	15.7
CASE 2	319.6	379.2	351.0	319.1	376.3	312.6	1.0	2.1	13.4
CASE 3	347.2	408.7	384.1	323.9	394.8	323.7	4.4	12.5	35.3
CASE 4	425.6	534.5	488.6	387.4	504.9	391.9	18.3	27.5	96.8
CASE 5	1144.0	1382.0	1253.0	1089.0	1289.0	1117.0	28.8	75.3	109.9
CASE 6	1114.0	1347.0	1248.0	995.0	1182.0	1020.0	46.2	102.9	159.2

Table 2
Percent Difference Micro versus BLAST

	TOTAL ENERGY CONSUMPTION			HEATING CONSUMPTION			COOLING CONSUMPTION		
PHOENIX	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE 1		-3.1%	7.9%		144.2%	118.0%		-21.0%	-18.5%
CASE 2		-8.3%	12.6%		87.1%	88.8%		-12.3%	-3.9%
CASE 3		-1.5%	18.6%		459.4%	268.8%		-15.1%	3.8%
CASE 4		13.5%	29.4%		394.2%	133.7%		-7.7%	23.8%
CASE 5		33.0%	10.5%		158.9%	90.7%		10.2%	-5.7%
CASE 6		23.5%	10.5%		164.8%	85.2%		10.2%	2.8%
COLUMBIA	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE 1		12.3%	22.6%		27.5%	20.9%		0.5%	25.9%
CASE 2		16.0%	20.2%		17.8%	1.6%		60.3%	262.1%
CASE 3		12.7%	24.6%		24.8%	9.5%		8.9%	113.8%
CASE 4		17.5%	28.9%		31.7%	5.7%		-2.1%	113.8%
CASE 5		29.1%	36.0%		20.8%	6.6%		97.5%	233.0%
CASE 6		27.7%	40.2%		24.4%	8.3%		58.2%	171.8%
BISMARCK	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE 1		13.7%	18.1%		19.7%	14.0%		101.9%	190.7%
CASE 2		18.6%	9.8%		17.9%	-2.0%		110.0%	1240.0%
CASE 3		17.7%	10.6%		21.9%	-0.1%		184.1%	702.3%
CASE 4		25.6%	14.8%		30.3%	1.2%		50.3%	429.0%
CASE 5		20.8%	9.5%		18.4%	2.6%		161.5%	281.6%
CASE 6		20.9%	12.0%		18.8%	2.5%		122.7%	244.6%

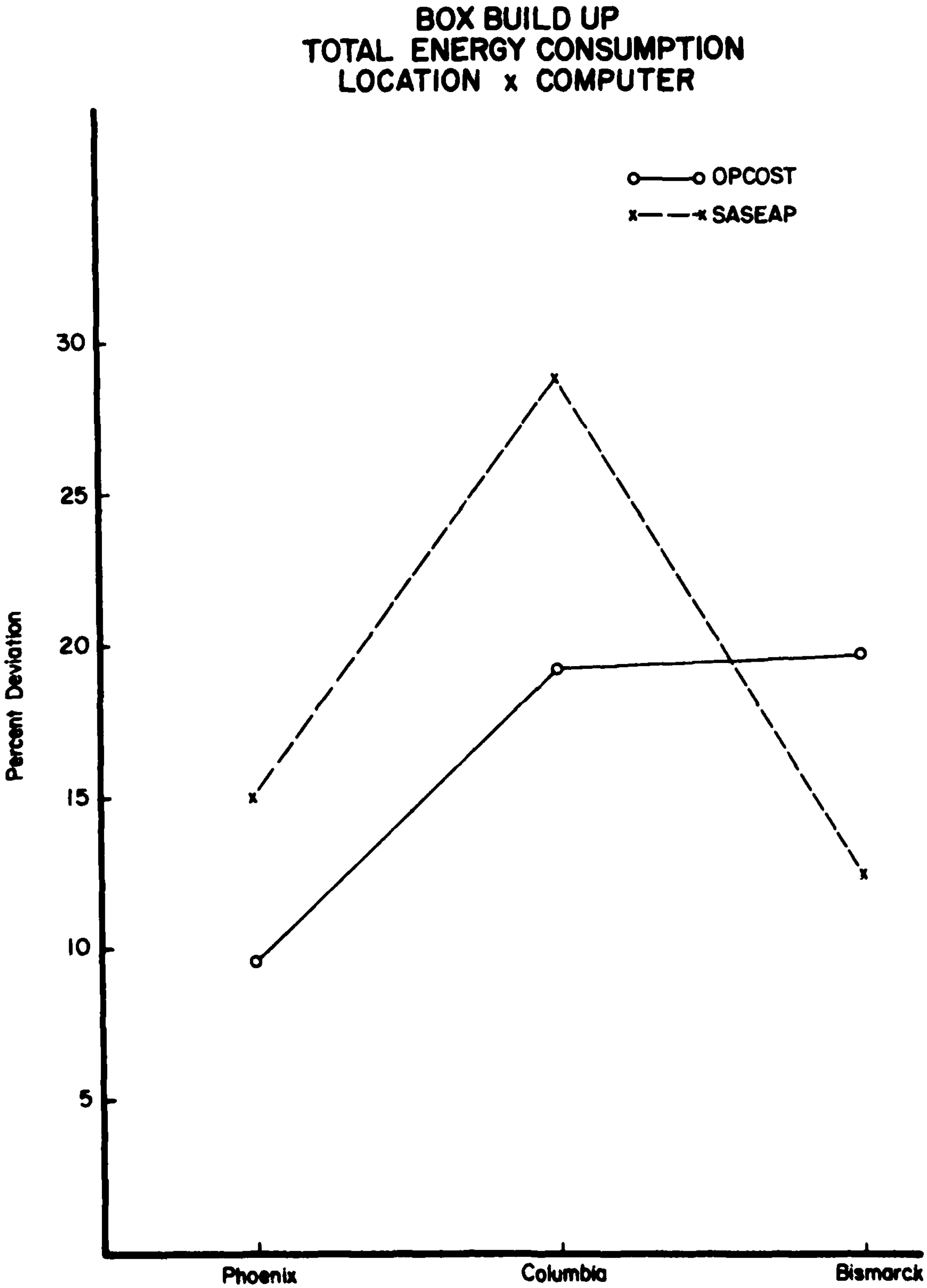


Figure 6. Analysis of variance results—box study.

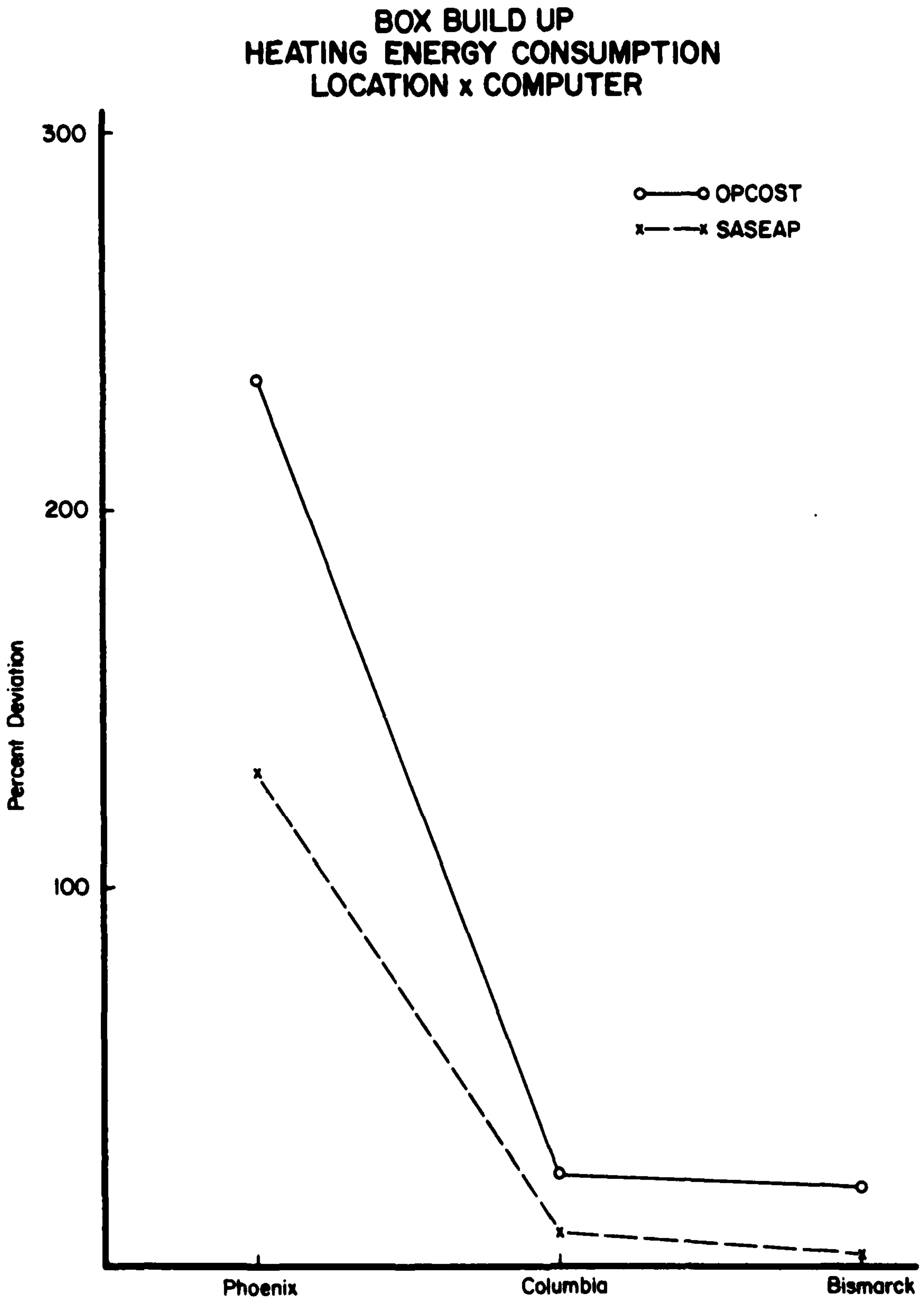


Figure 6. (Cont'd).

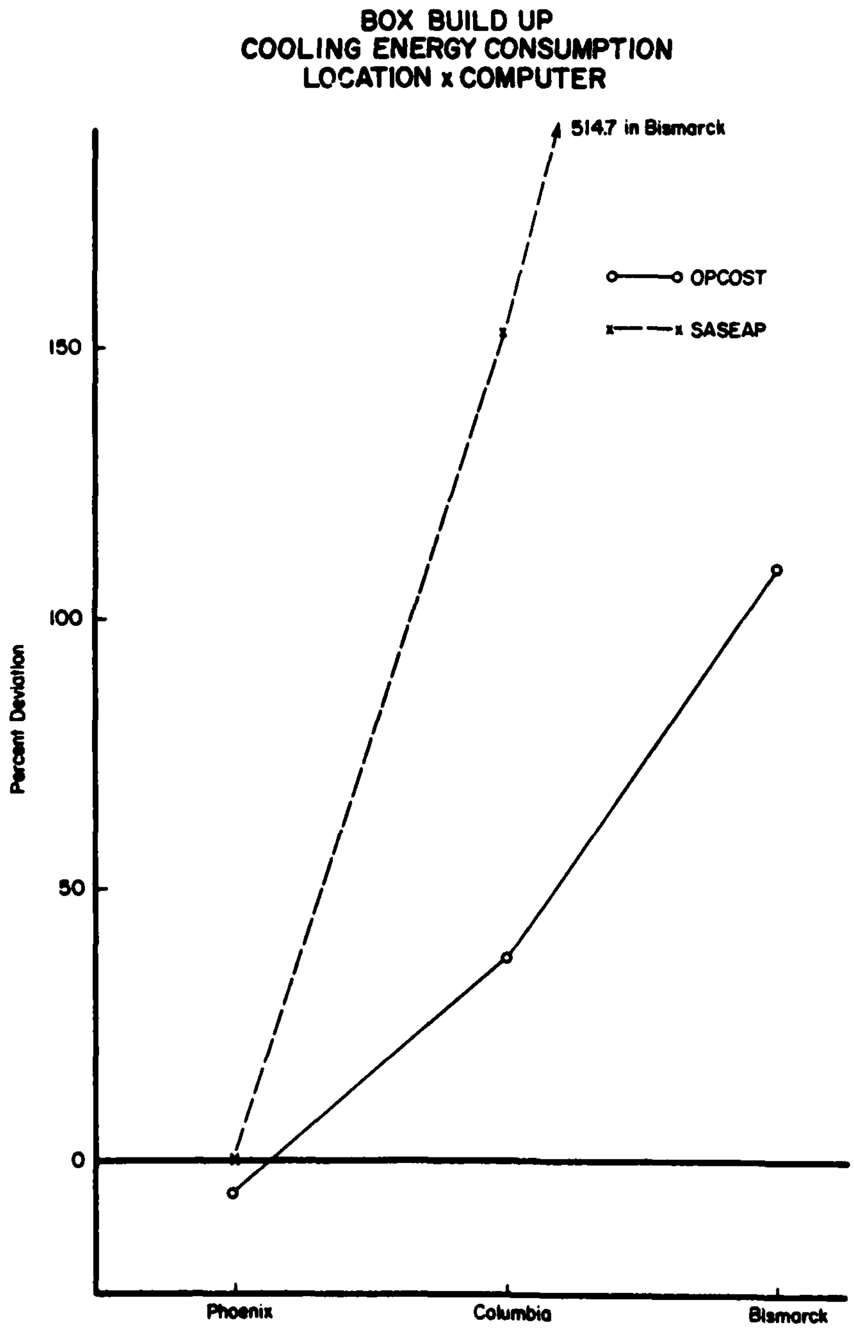


Figure 6. (Cont'd).

Table 3
Box Study Energy Savings Micro versus BLAST (Million Btu)

	TOTAL ENERGY CONSUMPTION			HEATING CONSUMPTION			COOLING CONSUMPTION		
PHOENIX	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE 2	8.4	14.9	2.9	-3.5	5.2	-0.6	18.8	7.8	3.5
CASE 3	-38.7	-47.1	-53.9	17.7	9.3	21.9	-66.8	-54.5	-75.7
CASE 4	-76.7	-112.7	-117.6	-2.2	-6.7	3.5	-74.0	-79.2	-121.2
CASE 5	-219.0	-339.5	-195.5	-66.3	-151.4	-122.7	-146.9	-201.7	-72.8
CASE 6	-107.0	-87.6	-118.1	20.0	48.5	41.1	-81.1	-89.3	-115.1
COLUMBIA	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE 2	-2.3	-9.3	1.6	-28.0	-19.5	-1.6	13.5	10.1	3.3
CASE 3	-12.9	-8.6	-24.1	14.6	6.5	2.7	-16.6	-15.1	-26.9
CASE 4	-54.8	-73.6	-78.9	-30.1	-50.3	-26.0	-24.7	-21.7	-52.8
CASE 5	-424.9	-577.5	-595.2	-378.8	-437.5	-405.1	-40.2	-126.3	-190.0
CASE 6	-18.8	-14.3	-54.7	77.1	75.7	73.5	-50.6	-45.7	-84.1
BISMARCK	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE 2	-22.4	-41.3	-0.1	-47.0	-50.7	-2.5	4.4	8.8	2.3
CASE 3	-27.6	-29.5	-33.1	-4.8	-18.5	-11.1	-3.4	-10.4	-21.9
CASE 4	-78.4	-125.8	-104.5	-63.5	-110.1	-68.2	-13.9	-15.0	-61.5
CASE 5	-718.4	-847.5	-764.4	-701.6	-784.1	-725.1	-10.5	-47.8	-13.1
CASE 6	30.0	35.0	5.0	94.0	107.0	97.0	-17.4	-27.6	-49.3

PERCENT DIFFERENCE MICRO VS. BLAST

	TOTAL ENERGY CONSUMPTION			HEATING CONSUMPTION			COOLING CONSUMPTION		
PHOENIX	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE 2		77.4%	-65.5%		-248.6%	-82.9%		-58.5%	-81.4%
CASE 3		21.7%	39.3%		-47.5%	23.7%		-18.4%	13.3%
CASE 4		46.9%	53.3%		204.5%	-259.1%		7.0%	63.8%
CASE 5		55.0%	-10.7%		128.4%	85.1%		37.3%	-50.4%
CASE 6		-18.1%	10.4%		142.5%	105.5%		10.1%	41.9%
COLUMBIA	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE 2		304.3%	-169.6%		-30.4%	-94.3%		-25.2%	-75.6%
CASE 3		-33.3%	86.8%		-55.5%	-81.5%		-9.0%	62.0%
CASE 4		34.3%	44.0%		67.1%	-13.6%		-12.1%	113.8%
CASE 5		35.9%	40.1%		15.5%	6.9%		214.2%	372.6%
CASE 6		-23.9%	191.0%		-1.8%	-4.7%		-9.7%	66.2%
BISMARCK	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE 2		84.4%	-99.6%		7.9%	-94.7%		100.0%	-47.7%
CASE 3		6.9%	19.9%		285.4%	131.3%		205.9%	544.1%
CASE 4		60.5%	33.3%		73.4%	7.4%		7.9%	342.4%
CASE 5		18.0%	6.4%		11.8%	3.3%		355.2%	24.8%
CASE 6		16.7%	-83.3%		13.8%	3.2%		58.6%	183.3%

Case F added a night set-back thermostat to Case A, which set back the heating temperature to 55°F for the period between 5 p.m. and 7 a.m. Both programs easily accepted the night set-back temperature; however, the SASEAP schedule was totally inputted, whereas OPCOST gave only a choice between four options, none of which was ideal.

Case G added all the Case B through Case F retrofit options simultaneously to Case A.

Input models for each program were prepared for each case, and simulations were performed for each case for three locations: Phoenix, AZ, Columbia, MO, and Bismarck, ND. Table 4 gives the simulation results.

To compare annual energy consumption predictions, percentage differences between predictions of the micro programs and BLAST were computed; these differences are shown in Table 5. The results show that for total annual energy consumption predictions the micro programs differ from BLAST by −4.5 to 80 percent, depending on the case and location. An analysis of variance performed on the data for total annual energy consumption indicated that the percentage difference between the micro programs and BLAST is strongly influenced by the location, the case, and the location/computer program interaction (see Figure 7). Similar results are shown in Table 5 and Figure 7 for the annual heating and cooling consumption predictions.

These results indicate that for the retrofit options studied for this building, the micro programs could not accurately predict the facility's annual energy consumption. Thus, in this case, the micro programs could not be used to compute accurate design energy budgets.

The data were analyzed further to determine if the microcomputer program results could be used to determine the possible energy savings from each retrofit option or to rank the retrofit options in order of energy savings. Table 6 shows the energy savings predicted by each program for each retrofit option and the percentage difference between BLAST's and the micro programs' predicted energy savings for each retrofit option. These data show that the predicted energy savings for each retrofit option are highly variable, depending on the case, the computer program, and the location. Fairly good agreement was obtained for some retrofit options (see Case E–reduction of window area), while very poor agreement was obtained for others (see Case C–addition of storm windows).

To determine if the programs could predict which retrofit options would give the most energy savings, Table 7 was created, showing the order of the cases from most to least energy use. This table shows that both OPCOST and SASEAP do adequately predict the proper order. Deviations in the order selected occurred when there was a small difference in the magnitude of the loads.

Weather File Information

Vendor-supplied weather data were used for the simulations in this evaluation. Since both OPCOST and SASEAP supply weather data with the programs, a designer might use these data, rather than hour-by-hour data, to enter his/her own weather files.

Study 1–Cases A and G

For this study, OPCOST and SASEAP simulations were repeated for Cases A and G of the box retrofit study in Evaluation 1, using vendor-supplied weather data.

For OPCOST, weather files were available for Phoenix, Columbia, and Bismarck; however, SASEAP-supplied weather files included only Phoenix as an exact match. Minneapolis, MN, and Bristol City, TN, were selected as being the most representative data geographically and climatologically from available SASEAP weather to use in place of Bismarck and Columbia, respectively. Table 8 shows simulation results and previous results. These results include both percentage differences between evaluation cases and predicted energy savings.

For OPCOST, where matches of location occurred, evaluation case differences ranged from 43 to +14 percent for total annual energy consumption. Predicted percentage energy savings were more conservative than those predicted in Evaluation 1 (for example, 45 percent versus 62 percent in Bismarck).

For SASEAP, both unmatched location simulations showed the same percentage differences between the two simulations (i.e., both cases were 20 percent different from Evaluation 1 in the Columbia equivalent). However, in Phoenix the matched location–the SASEAP percentage differences between the two simulations were −7 percent (Case A) and 61 percent (Case G). Further investigation showed that SASEAP data for Phoenix carried the designation "for continuous operation only"; thus, this data should not have been applied to a night set-back simulation. However, SASEAP did not contain an adequate definition of "continuous operation." Except for Phoenix, the

Table 4
Box Retrofit Study Annual Energy Consumption (Million Btu)

	TOTAL ENERGY CONSUMPTION			HEATING CONSUMPTION			COOLING CONSUMPTION		
PHOENIX	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE A	573.5	708.9	633.8	54.9	145.4	101.7	450.1	496.0	462.9
CASE B	533.7	626.6	591.7	37.0	107.4	73.9	434.2	452.0	448.6
CASE C	558.1	653.8	602.3	65.3	122.5	87.1	422.7	466.8	446.0
CASE D	548.1	644.6	586.4	67.1	121.1	84.7	410.3	459.1	432.5
CASE E	484.3	615.3	560.0	56.1	152.6	120.3	360.7	400.7	370.5
CASE F	384.7	515.1	395.1	14.4	119.3	36.9	315.4	337.9	302.0
CASE G	283.0	309.4	270.4	18.0	62.5	24.3	211.6	195.3	189.9
COLUMBIA	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE A	691.5	882.9	969.3	484.7	602.9	525.1	137.9	218.1	374.8
CASE B	598.3	785.6	817.8	395.1	492.2	422.5	140.5	231.7	325.9
CASE C	638.9	787.3	907.2	438.0	524.9	462.8	131.4	200.6	375.0
CASE D	620.0	766.8	889.2	418.9	508.6	452.9	132.0	196.4	366.9
CASE E	630.1	795.8	920.0	466.5	580.0	514.6	95.0	154.1	336.0
CASE F	407.8	563.4	632.1	251.2	382.7	288.7	100.7	127.5	234.1
CASE G	237.8	309.1	429.0	119.2	191.1	207.0	66.4	67.1	162.3
BISMARCK	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE A	1114.0	1347.0	1248.0	995.0	1182.0	1020.0	46.2	102.9	159.2
CASE B	934.1	1156.0	1058.0	823.5	986.8	838.6	45.5	108.4	149.9
CASE C	1021.0	1209.0	1131.0	905.0	1040.0	903.7	43.8	106.7	158.5
CASE D	985.8	1184.0	1108.0	865.7	1016.0	885.3	49.4	106.8	153.8
CASE E	1052.0	1234.0	1183.0	950.6	1114.0	982.3	29.6	58.5	132.1
CASE F	766.8	944.3	911.3	669.6	832.8	729.4	36.0	58.3	120.6
CASE G	349.3	513.0	585.7	274.6	438.1	445.3	21.9	24.0	79.1

Table 5
Box Retrofit Study Percent Difference Micro versus BLAST

	TOTAL ENERGY CONSUMPTION			HEATING CONSUMPTION			COOLING CONSUMPTION		
PHOENIX	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE A		23.6%	10.5%		164.8%	85.2%		10.2%	2.8%
CASE B		17.4%	10.9%		190.3%	99.7%		4.1%	3.3%
CASE C		17.1%	7.9%		87.6%	33.4%		10.4%	5.5%
CASE D		17.6%	7.0%		80.5%	26.2%		11.9%	5.4%
CASE E		27.0%	15.6%		172.0%	114.4%		11.1%	2.7%
CASE F		33.9%	2.7%		728.5%	156.3%		7.1%	-4.2%
CASE G		9.3%	-4.5%		247.2%	35.0%		-7.7%	-10.3%
COLUMBIA	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE A		27.7%	40.2%		24.4%	8.3%		58.2%	171.8%
CASE B		31.3%	36.7%		24.6%	6.9%		64.9%	132.0%
CASE C		23.2%	42.0%		19.8%	5.7%		52.7%	185.4%
CASE D		23.7%	43.4%		21.4%	8.1%		48.8%	178.0%
CASE E		26.3%	46.0%		24.3%	10.3%		62.2%	253.7%
CASE F		38.2%	55.0%		52.3%	14.9%		26.6%	132.5%
CASE G		30.0%	80.4%		60.3%	73.7%		1.1%	144.4%
BISMARCK	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE A		20.9%	12.0%		18.8%	2.5%		122.7%	244.6%
CASE B		23.8%	13.3%		19.8%	1.8%		138.2%	229.5%
CASE C		18.4%	10.8%		14.9%	-0.1%		143.6%	261.9%
CASE D		20.1%	12.4%		17.4%	2.3%		116.2%	211.3%
CASE E		17.3%	12.5%		17.2%	3.3%		97.6%	346.3%
CASE F		23.1%	18.8%		24.4%	8.9%		61.9%	235.0%
CASE G		46.9%	67.7%		59.5%	62.2%		9.6%	261.2%

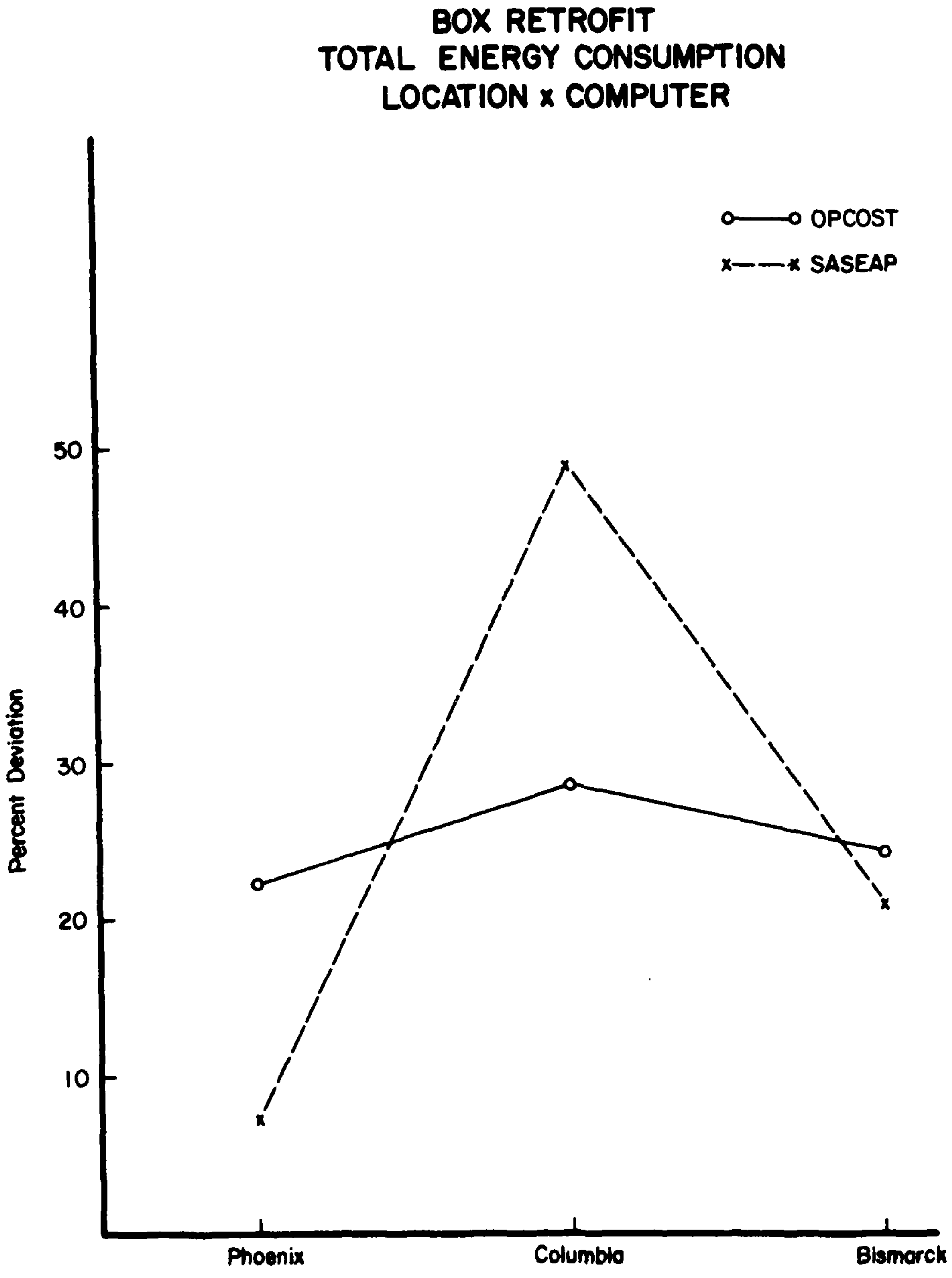


Figure 7. Annual heating and cooling consumption predictions--box retrofit study.

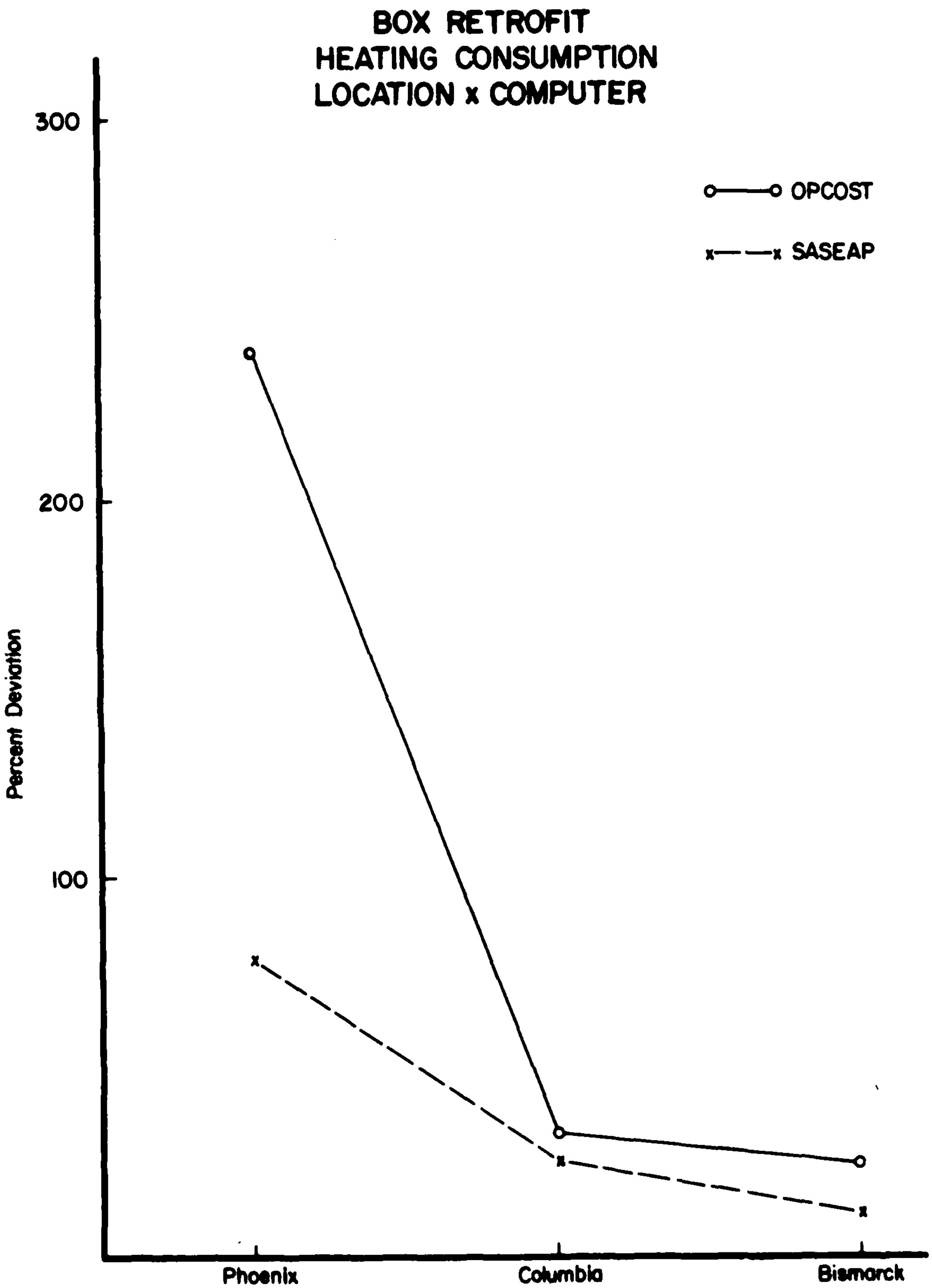


Figure 7. (Cont'd).

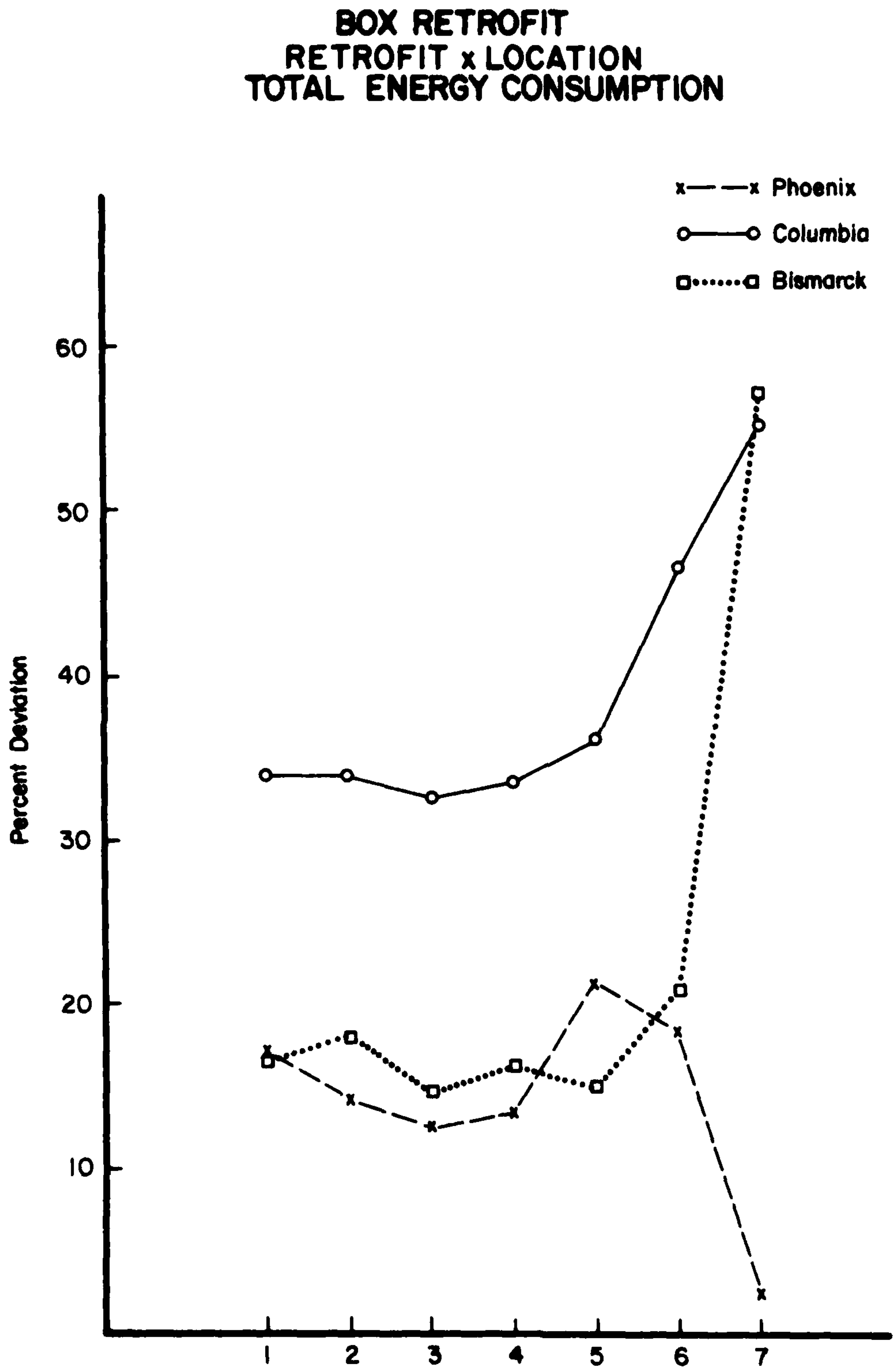


Figure 7. (Cont'd).

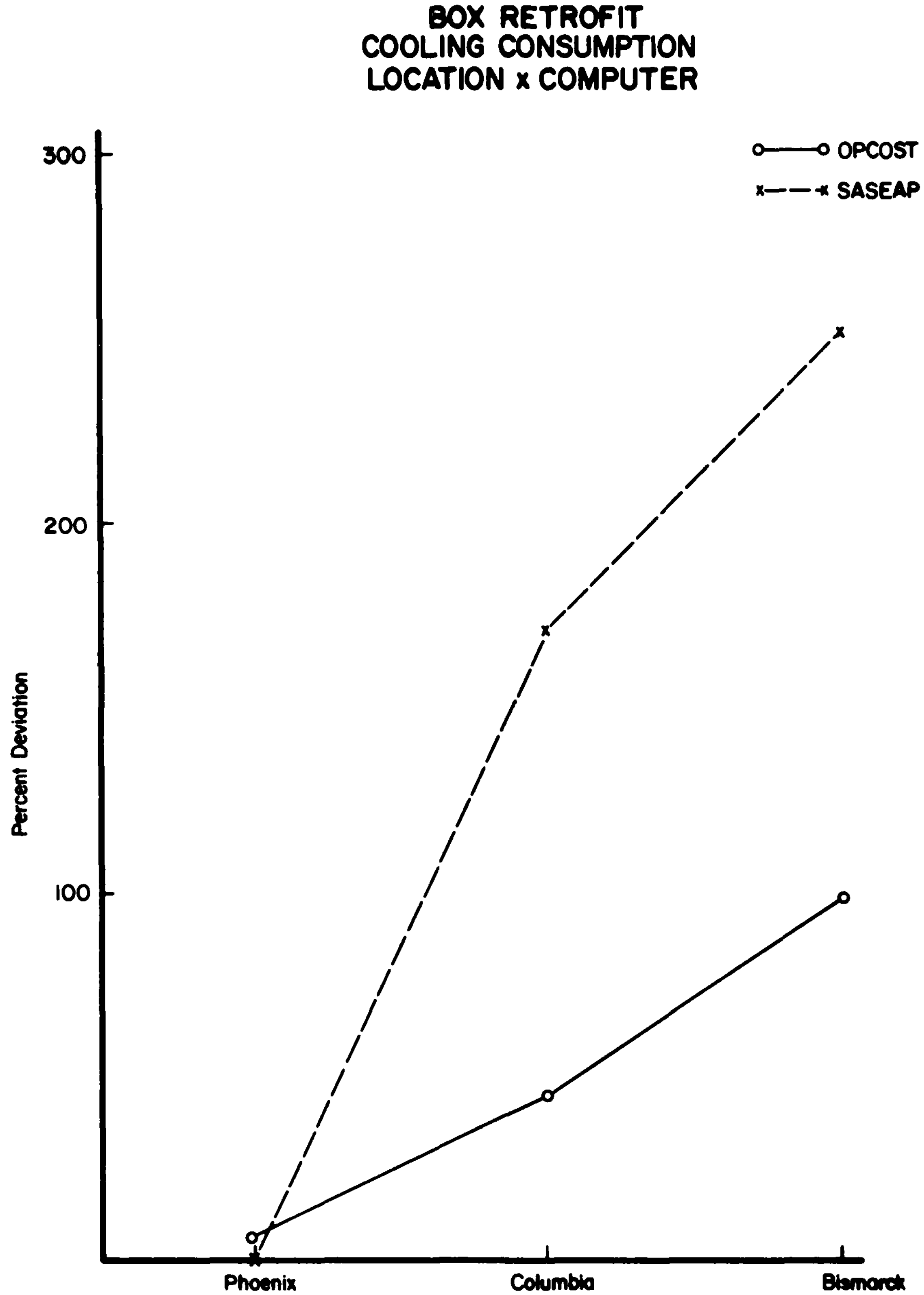


Figure 7. (Cont'd).

Table 6
Box Retrofit Study Energy Savings (Million Btu)

	TOTAL ENERGY CONSUMPTION			HEATING CONSUMPTION			COOLING CONSUMPTION		
PHOENIX	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE B	39.8	82.3	42.1	17.9	38.0	27.8	15.9	44.0	14.3
CASE C	15.4	55.1	31.5	-10.4	22.9	14.6	27.4	29.2	16.9
CASE D	25.4	64.3	47.4	-12.2	24.3	17.0	39.8	36.9	30.4
CASE E	89.2	93.6	73.9	-1.2	-7.2	-18.6	89.4	95.3	92.4
CASE F	188.8	193.8	238.7	40.5	26.1	64.8	134.7	158.1	160.9
CASE G	290.5	399.5	363.4	36.9	82.9	77.4	238.5	300.7	273.0
COLUMBIA	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE B	93.2	97.3	151.5	89.6	110.7	102.6	-2.6	-13.6	48.9
CASE C	52.6	95.6	62.1	46.7	78.0	62.3	6.5	17.5	-0.2
CASE D	71.5	116.1	80.1	65.8	94.3	72.2	5.9	21.7	7.9
CASE E	61.4	87.1	49.3	18.2	22.9	10.5	42.9	64.0	38.8
CASE F	283.7	319.5	337.2	233.5	220.2	236.4	37.2	90.6	140.7
CASE G	453.7	573.8	540.3	365.5	411.8	318.1	71.5	151.0	212.5
BISMARCK	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE B	179.9	191.0	190.0	171.5	195.2	181.4	0.7	-5.5	9.3
CASE C	93.0	138.0	117.0	90.0	142.0	116.3	2.4	-3.8	0.7
CASE D	128.2	163.0	140.0	129.3	166.0	134.7	-3.2	-3.9	5.4
CASE E	62.0	113.0	65.0	44.4	68.0	37.7	16.6	44.4	27.1
CASE F	347.2	402.7	336.7	325.4	349.2	290.6	10.2	44.6	38.6
CASE G	764.7	834.0	662.3	720.4	743.9	574.7	24.3	78.9	80.1

BOX RETROFIT STUDY PERCENT DIFFERENCE IN ENERGY SAVINGS MICRO VS. BLAST

	TOTAL ENERGY CONSUMPTION			HEATING CONSUMPTION			COOLING CONSUMPTION		
PHOENIX	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE B		106.8%	5.8%		112.3%	55.3%		176.7%	-10.1%
CASE C		257.8%	104.5%		-320.2%	-240.4%		6.6%	-38.3%
CASE D		153.1%	86.6%		-299.2%	-239.3%		-7.3%	-23.6%
CASE E		4.9%	-17.3%		500.0%	1450.0%		6.6%	3.4%
CASE F		2.6%	26.4%		-35.6%	60.0%		17.4%	19.5%
CASE G		37.5%	25.1%		124.7%	109.8%		26.1%	14.5%
COLUMBIA	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE B		4.4%	62.6%		23.5%	14.5%		423.1%	-1980.8%
CASE C		81.7%	18.1%		67.0%	33.4%		169.2%	-103.1%
CASE D		62.4%	12.0%		43.3%	9.7%		267.8%	33.9%
CASE E		41.9%	-19.7%		25.8%	-42.3%		49.2%	-9.6%
CASE F		12.6%	18.9%		-5.7%	1.2%		143.5%	278.2%
CASE G		26.5%	19.1%		12.7%	-13.0%		111.2%	197.2%
BISMARCK	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE B		6.2%	5.6%		13.8%	5.8%		-885.7%	1228.6%
CASE C		48.4%	25.8%		57.8%	29.2%		-258.3%	-70.8%
CASE D		27.1%	9.2%		28.4%	4.2%		21.9%	-268.8%
CASE E		82.3%	4.8%		53.2%	-15.1%		167.5%	63.3%
CASE F		16.0%	-3.0%		7.3%	-10.7%		337.3%	278.4%
CASE G		9.1%	-13.4%		3.3%	-20.2%		224.7%	229.6%

Table 7
Ranking of Retrofit Options—Box Retrofit Study
(From Highest Consumption to Lowest)

	TOTAL ENERGY CONSUMPTION			HEATING CONSUMPTION			COOLING CONSUMPTION		
	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
PHOENIX	CASE A	A*	A	D	E	E	A	A	A*
	C	C	C	C	A	A	B	C	B
	D	D	B	E	C	C	C	D	C
	B	B	D	A	D	D	D	B	D
	E	E	E	B	F	B	E	E	E
	F	F	F	G	B	F	F	F	F
	G	G	G	F	G	G	G	G	G
	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
COLUMBIA	A	A	A	A	A*	A*	B	B	C
	C	E	E	E	E	E	A	A	A
	E	C	C	C	C	C	D	C	D
	D	B	D	D	D	D	C	D	E
	B	D	B	B	B	B	F	E	B
	F	F	F	F	F	F	E	F	F
	G	G	G	G	G	G	G	G	G
	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
BISMARCK	A	A*	A*	A	A*	A*	D	B	A
	E	E	E	E	E	E	A	D	C
	C	C	C	C	C	C	B	C	D
	D	D	D	D	D	D	C	A	B
	B	B	B	B	B	B	F	E	E
	F	F	F	F	F	F	E	F	F
	G	G	G	G	G	G	G	G	G

* INDICATES AN EXACT MATCH WITH BLAST

predicted percentage of energy savings was the same (Bismarck replacement) or more conservative (Columbia replacement) than predicted in Evaluation 1.

These results indicate sensitivity of the programs to the supplied weather data. They also indicate that caution is needed when choosing a replacement location, with respect both to climatological considerations and to the applicability of chosen data to the case being studied.

For comparison, the same BLAST cases were simulated, substituting Typical Meterological Year (TMY) data for the Test Reference Year (TRY) data in Columbia. Differences between the two weather simulations were 4 to 5 percent for both total and heating, while cooling differences were 8 to 10 percent (TMY data has more accurate average solar data). Predicted percentage savings were 65 percent for TMY data and 66 percent for the original TRY data. Thus, substitution of representative weather data should not create great (>15 percent) fluctuations in results.

Study 2 Case D

For this study, some design options that can be simulated with BLAST, but not with the micro programs, were added to Case D of the box retrofit study. The glass was increased to 50 percent of the south wall area. Overhangs were added to the south face of the building to offset the effect of increased glazing.

Table 8
Results for Vendor Supplied Weather Data Runs – Box Retrofit Study
(Million Btu)

	TOTAL ENERGY CONSUMPTION		HEATING CONSUMPTION		COOLING CONSUMPTION	
PHOENIX	OPCOST	SASEAP	OPCOST	SASEAP	OPCOST	SASEAP
CASE A						
USER WEATH DATA	708.9	633.8	145.4	101.7	496.0	462.9
VENDOR WEATH DATA	680.6	681.9	95.5	111.2	517.1	501.5
% DIFFERENCE	4.0%	-7.6%	34.3%	-9.3%	-4.3%	-8.3%
CASE G						
USER WEATH DATA	309.4	270.4	62.5	24.3	195.3	189.9
VENDOR WEATH DATA	317.2	105.2	37.9	7.3	227.8	50.6
% DIFFERENCE	-2.5%	61.1%	39.4%	70.0%	-16.6%	73.4%
% SAVINGS USER	56.4%	57.3%	57.0%	76.1%	60.6%	59.0%
% SAVINGS VENDOR	53.4%	84.6%	60.3%	93.4%	55.9%	89.9%
COLUMBIA	OPCOST	SASEAP	OPCOST	SASEAP	OPCOST	SASEAP
CASE A						
USER WEATH DATA	882.9	969.3	602.9	525.1	218.1	374.8
VENDOR WEATH DATA	847.2	777.1	599.7	425.1	184.1	282.9
% DIFFERENCE	4.0%	19.8%	0.5%	19.0%	15.6%	24.5%
CASE G						
USER WEATH DATA	309.1	429.0	191.1	207.0	67.1	162.3
VENDOR WEATH DATA	421.2	347.8	293.5	148.5	76.9	140.5
% DIFFERENCE	-36.3%	18.9%	-53.6%	28.3%	-14.6%	13.4%
% SAVINGS USER	65.0%	55.7%	68.3%	60.6%	69.2%	56.7%
% SAVINGS VENDOR	50.3%	55.2%	51.1%	65.1%	58.2%	50.3%
BISMARCK	OPCOST	SASEAP	OPCOST	SASEAP	OPCOST	SASEAP
CASE A						
USER WEATH DATA	1347.0	1248.0	1182.0	1020.0	102.9	159.2
VENDOR WEATH DATA	1347.0	1093.0	1228.0	839.6	54.8	185.0
% DIFFERENCE	0.0%	12.4%	-3.9%	17.7%	46.7%	-16.2%
CASE G						
USER WEATH DATA	513.0	585.7	438.1	445.3	24.0	79.1
VENDOR WEATH DATA	734.7	517.1	663.3	359.1	20.6	96.9
% DIFFERENCE	-43.2%	11.7%	-51.4%	19.4%	14.2%	-22.5%
% SAVINGS USER	61.9%	53.1%	62.9%	56.3%	76.7%	50.3%
% SAVINGS VENDOR	45.5%	52.7%	46.0%	57.2%	62.4%	47.6%

Building heating/cooling controls were changed to night and weekend set-back. A new BLAST model was prepared which included these options. Also, the BLAST exact solar distribution option was used, which distributes the amount of radiation falling on each surface of a zone. New input models for the micro program could only reflect the increased glass area and set-back. The addition of overhangs could not be simulated. New simulations were performed for Phoenix, Columbia, and Bismarck using vendor-supplied weather data.

Table 9 gives the results of this study, which show that there are substantial differences in the predicted energy savings from the added design options, depending on which program is used.

Table 9
Results for More Complex Design Options—Case D (Million Btu)

	TOTAL ENERGY CONSUMPTION			HEATING CONSUMPTION			COOLING CONSUMPTION		
PHOENIX	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
ORIGINAL	283.0	317.2	105.2	18.0	37.9	7.3	211.6	227.8	50.6
DETAILED	366.8	329.2	111.7	6.8	9.2	1.2	308.7	267.9	64.1
% DIFFER	-29.6%	-3.8%	-6.2%	62.2%	75.7%	83.6%	-45.9%	-17.6%	-26.7%
COLUMBIA	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
ORIGINAL	237.8	421.2	347.8	119.2	293.5	148.5	66.4	76.9	140.5
DETAILED	236.5	304.9	298.0	83.6	149.2	90.2	102.8	104.9	152.4
% DIFFER	0.5%	27.6%	14.3%	29.9%	49.2%	39.3%	-54.8%	-36.4%	-8.5%
BISMARCK	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
ORIGINAL	349.3	734.7	517.1	274.6	663.3	359.1	21.9	20.6	96.9
DETAILED	396.9	487.0	451.7	307.2	388.9	264.9	37.2	46.2	129.0
% DIFFER	-13.6%	33.7%	12.6%	-11.9%	41.4%	26.2%	-69.9%	-124.3%	-33.1%

Ambiguity of Input Requirements

Both the SASEAP and OPCOST programs have entries which are not well-defined in the user's manual. For SASEAP, these inputs are:

1. Intermediate temperatures for analysis
2. Color correction factor.

For OPCOST the inputs are:

1. Building weight
2. Wall and roof color.

From discussion with Sud Associates, SASEAP's "intermediate temperatures for analysis" were clarified to be two temperature bins derived from two temperatures relating directly to the building being simulated. The first (lower) temperature bin is selected to account for interval loads which make up for heat loss (i.e., the bin of the temperature when the building begins to need heating). This was estimated to be either the 57.5- or the 52.5-degree bin. Also, the upper temperature bin is selected to account for the transmission and solar gain factors which impose a heat gain (i.e., the bin of the temperature when the building begins to need cooling). This was estimated to be the 77.5-degree bin.

From the SASEAP User's Manual,[18] suggestions on the range of the color correction factor varied from 0.65 to 1.0 for walls, and from 0.5 to 1.0 for roofs. These values seemed to correlate to the ASHRAE percentage of absorptance. Thus, the color correction factor inputs were approximated by scaling the percentage of absorptance of the actual ASHRAE roof/wall against SASEAP's allowed color correction factors.

The OPCOST building weight input allowed for two choices: light or medium-heavy. Since the OPCOST User's Manual[19] furnished no guidelines, the example buildings were inputted as medium-heavy because of the amount of concrete the structures contained.

The OPCOST wall and roof color inputs also allowed for two choices: light or dark. Again, this

[18] *Sud Associates Simplified Energy Analysis Program (SASEAP) User's Manual.*
[19] *Operating Cost Analysis Version 1.5 (OPCOST) User's Manual.*

input was assumed to relate to percent absorptance. Since the plans of these buildings indicated that absorptance was low for the roof and relatively high for the walls, the OPCOST inputs were light for roofs and dark for walls.

Summary of Results

Table 10 is a composite of the total energy consumption data for the box study at the three locations. Graphs corresponding to Table 10 are shown in Figure 8. Table 11 shows the percentage of deviation between the BLAST-computed and the micro-computed total energy consumption. The deviations range as high as 80 percent, although most tend to range from 10 to 40 percent. These results are outside the 10 percent variation set in ETL-1110-3-309 as being within the acceptable range for comparing energy budgets. Graphs illustrating Table 11 are shown in Figure 9; solid lines have been drawn at the +15 and −15 percent levels to delineate the guideline from ETL-1110-3-309.

Of more concern, however, are the results shown in Tables 12 and 13. Table 12 summarizes the impact on total energy consumption of the individual design features (Cases 2 through 6) and the energy savings of the various retrofit options (Cases B through G) as calculated by BLAST and by the micro programs. The graph in Figure 10 illustrates Table 12. Table 13 shows the deviations between the energy impacts or savings calculated by BLAST and those calculated by the micro programs. Here, the errors range as high as 300 percent, with many errors exceeding 40 percent. Since the final case (G) does not exhibit these wide swings, the modeling of the accumulation of the various design features/options appears to cause canceling effects, so that the micro programs predict total-energy/final-energy consumption better than they predict a change resulting from a particular design feature. The graph in Figure 11 illustrates Table 13; lines are shown at +15 and −15 percent levels.

These tables show no trends in the results. That is, the micro programs may agree with BLAST on one feature, but yet not agree on another feature across the three climate regions. Furthermore, the two micro programs do not agree even though they use the same calculational principle. For example, in Case B in Table 13 (the effect of reduced ventilation), OPCOST overpredicted the energy savings in Phoenix by a factor of two, while SASEAP gave excellent agreement; in Columbia, the results were just the opposite, and for Bismarck, both gave good results.

Although these results do not represent an exhaustive study of microcomputer energy analysis programs, they do indicate that there are several potential problems with these programs. The buildings chosen for this study (lightweight small buildings with simple HVAC systems and controls) were the type that bin method programs should be best suited for studying. The results would indicate that more work is needed in developing these programs.

The variations between these two micro programs also indicate that the implementation of the calculational method is a critical factor. Thus, there may be other programs on the market which would give better results, but it would be hard to find out if this is true without an exhaustive study.

Although these evaluations do not represent an exhaustive study, they indicate that there are several potential problems with using microcomputer-based energy analysis programs. Because of the technique used to perform energy analysis in the micro programs, these programs should be most accurate when simulating simple, lightweight buildings which are dominated by envelope loads. Both buildings used in this study are of that type, but the results indicate that the programs had difficulty predicting the facilities' total energy consumption.

If the intended use of the programs is to rank new design or retrofit options, the micro programs' results are more favorable. In almost every case, the micro programs ranked the design options in the same order as BLAST. However, the absolute energy savings predicted by the program for the design options deviated significantly from the BLAST predictions. This could be very important to the designer if the energy savings figure is to be used to justify the cost of the design options. Thus, the micro programs could be used to rank the design options studied for these buildings in the correct order, but not to determine the absolute energy savings of each option. The graphs in Figure 12 illustrate the percent savings, but compare these to Table 13 graphs.

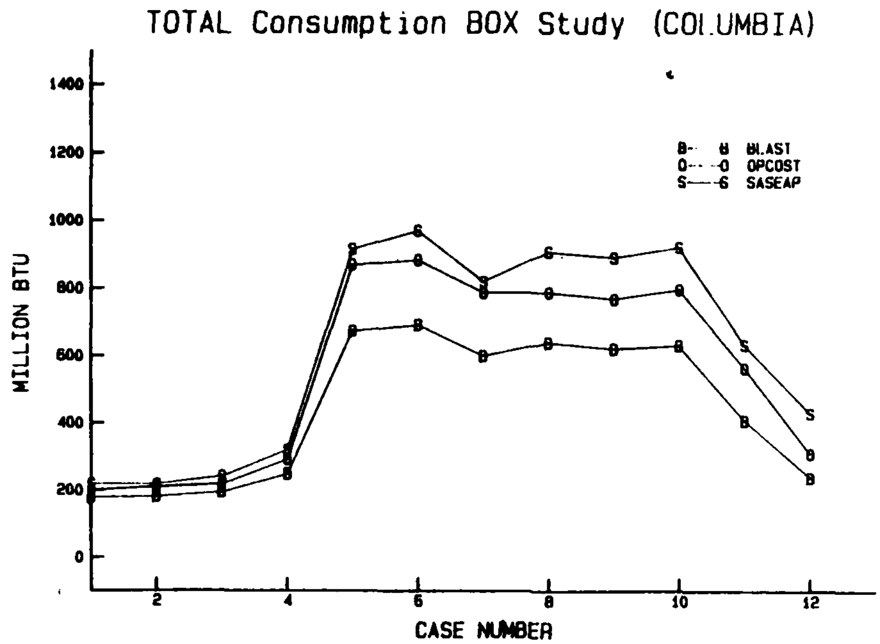
While these results cannot be generalized directly to other facility types, they do indicate that the micro programs had difficulty predicting the absolute energy consumption and absolute energy savings of the two simple facilities studied. Therefore, if the programs are to be used for predicting absolute energy consumption or absolute energy savings for larger or more complicated facilities, substantial error will probably result.

Table 10
Box Study Total Energy Consumption (Million Btu)

	PHOENIX			COLUMBIA			BISMARCK		
	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE 1	140.5	136.1	151.6	177.8	199.6	218.0	297.2	337.9	350.9
CASE 2	132.1	121.2	148.7	180.1	208.9	216.4	319.6	379.2	351.0
CASE 3	170.8	168.3	202.6	193.0	217.5	240.5	347.2	408.7	384.1
CASE 4	247.5	281.0	320.2	247.8	291.1	319.4	425.6	534.5	488.6
CASE 5	466.5	620.5	515.7	672.7	868.6	914.6	1144.0	1382.0	1253.0
CASE 6/A	573.5	708.1	633.8	691.5	882.9	969.3	1114.0	1347.0	1248.0
CASE B	533.7	626.6	591.7	598.3	785.6	817.8	934.1	1156.0	1058.0
CASE C	558.1	653.8	602.3	638.9	787.3	907.2	1021.0	1209.0	1131.0
CASE D	548.1	644.6	586.4	620.0	766.8	889.2	985.8	1184.0	1108.0
CASE E	484.3	615.3	560.0	630.1	795.8	920.0	1052.0	1234.0	1183.0
CASE F	384.7	515.1	395.1	407.8	563.4	632.1	766.8	944.3	911.3
CASE G	283.0	309.4	270.4	237.8	309.1	429.0	349.3	513.0	585.7

Table 11
Percent Deviation in Total Energy Consumption Blast versus Micro
100*(Micro-BLAST)/BLAST

	PHOENIX			COLUMBIA			BISMARCK		
	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE 1		-3.1%	7.9%		12.3%	22.6%		13.7%	18.1%
CASE 2		-8.3%	12.6%		16.0%	20.2%		18.6%	9.8%
CASE 3		-1.5%	18.6%		12.7%	24.6%		17.7%	10.6%
CASE 4		13.5%	29.4%		17.5%	28.9%		25.6%	14.8%
CASE 5		33.0%	10.5%		29.1%	36.0%		20.8%	9.5%
CASE 6/A		23.5%	10.5%		27.7%	40.2%		20.9%	12.0%
CASE B		17.4%	10.9%		31.3%	36.7%		23.8%	13.3%
CASE C		17.1%	7.9%		23.2%	42.0%		18.4%	10.8%
CASE D		17.6%	7.0%		23.7%	43.4%		20.1%	12.4%
CASE E		27.0%	15.6%		26.3%	46.0%		17.3%	12.5%
CASE F		33.9%	2.7%		38.2%	55.0%		23.1%	18.8%
CASE G		9.3%	-4.5%		30.0%	80.4%		46.9%	67.7%



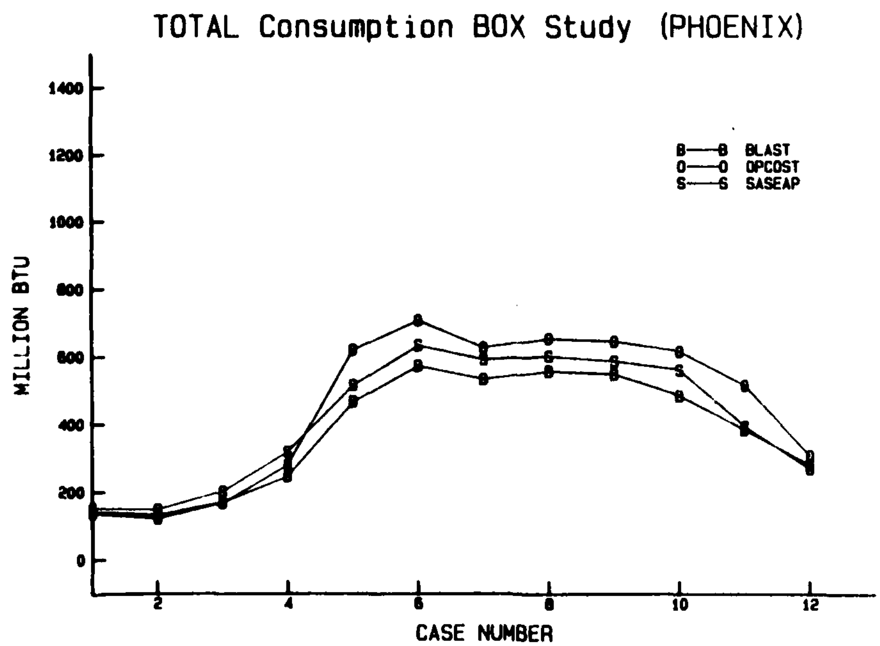
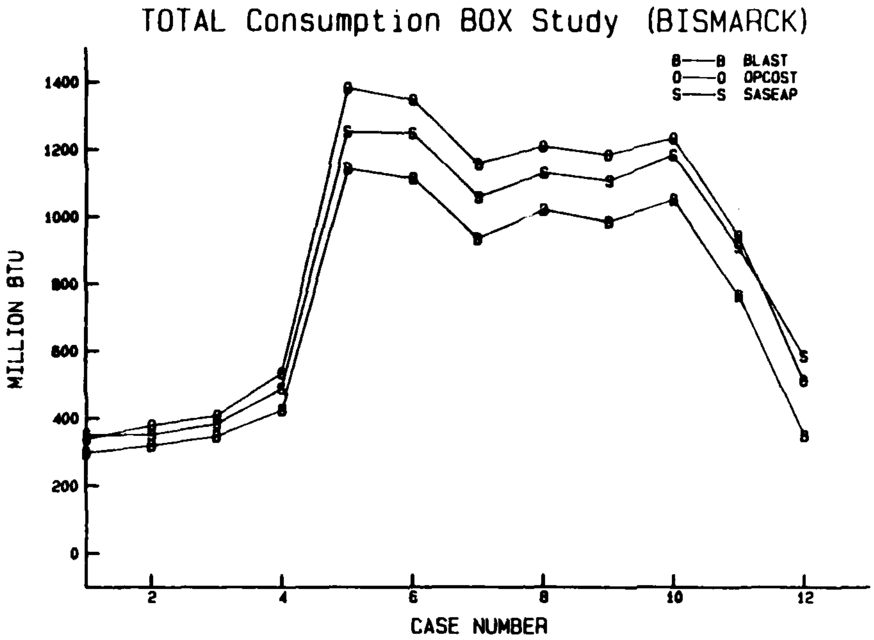


Figure 8. Total energy consumption at the three locations.



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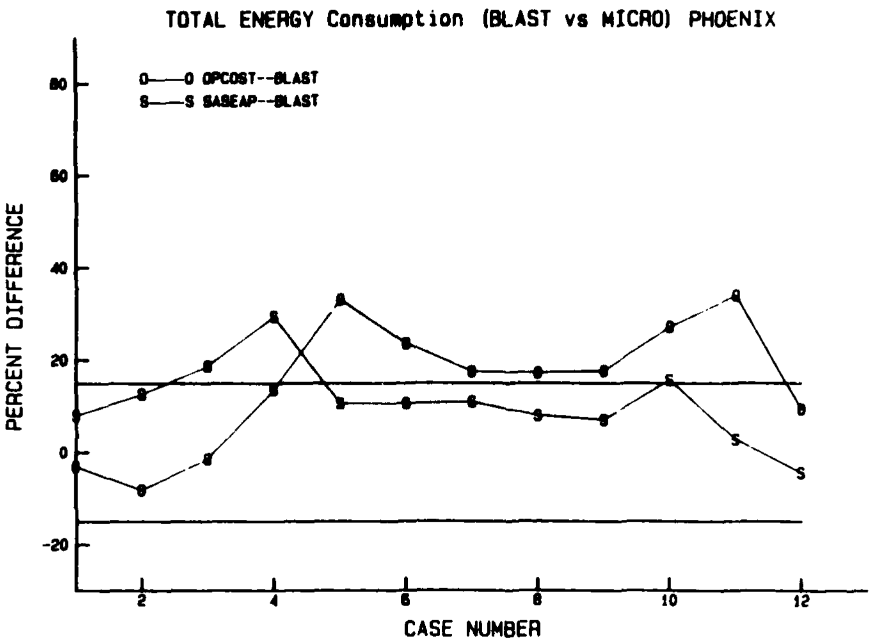
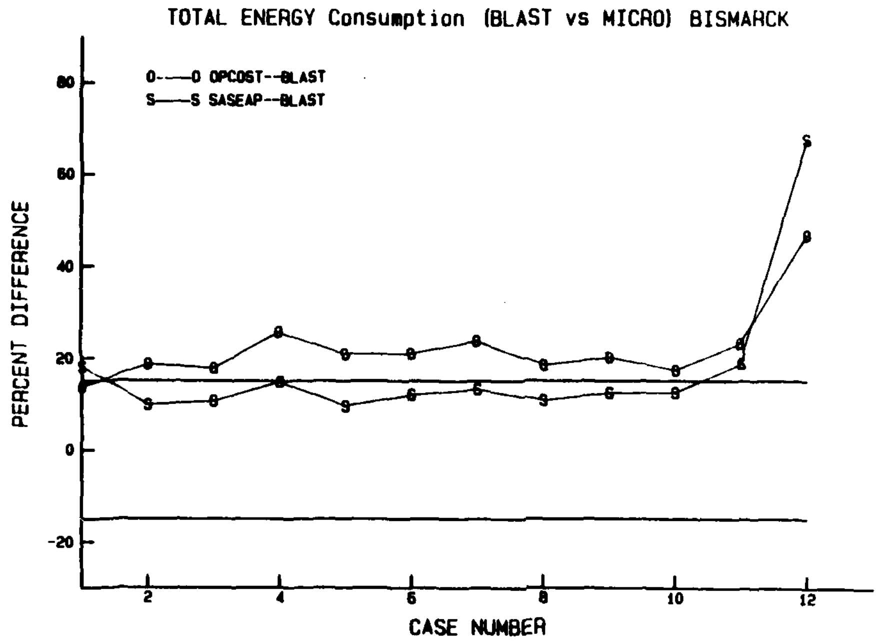


Figure 9. Deviations between BLAST-computed and micro-computed total energy consumption.



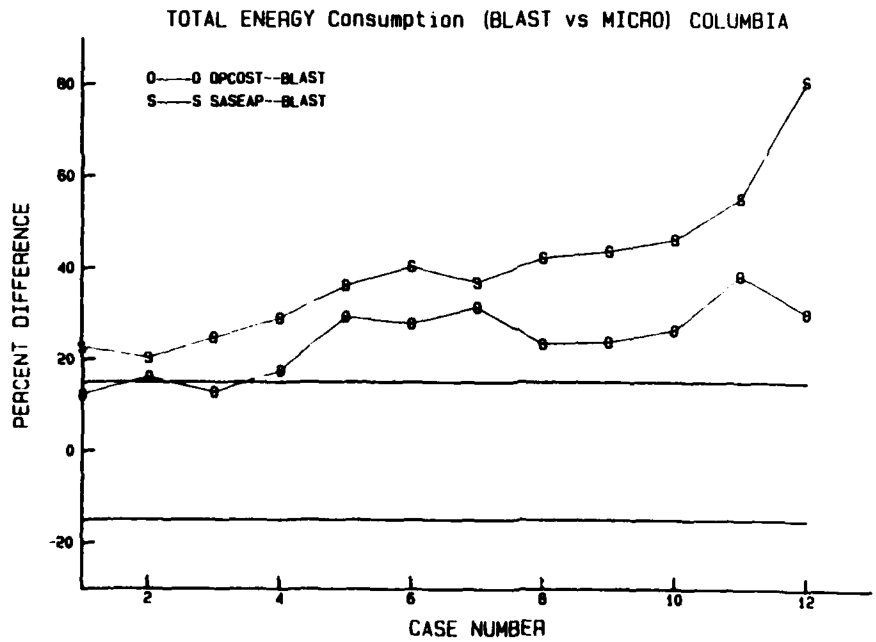


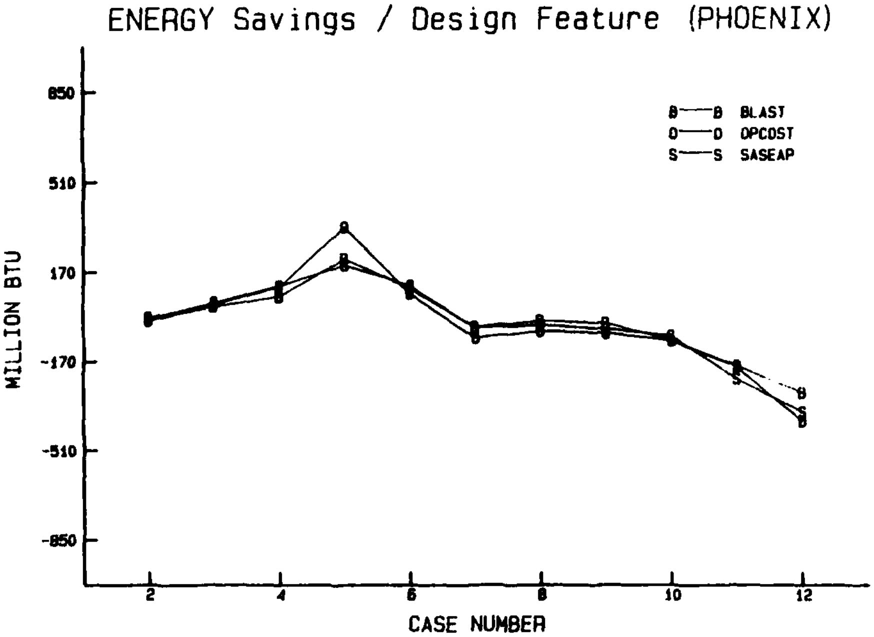
Figure 9. (Cont'd).

Table 12
Box Study Energy Savings Per Design Feature (Million Btu)

	PHOENIX			COLUMBIA			BISMARCK		
	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE 2	8.4	14.9	2.9	-2.3	-9.3	1.6	-22.4	-41.3	-0.1
CASE 3	-38.7	-47.1	-53.9	-12.9	-8.6	-24.1	-27.6	-29.5	-33.1
CASE 4	-76.7	-112.7	-117.6	-54.8	-73.6	-78.9	-78.4	-125.8	-104.5
CASE 5	-219.0	-339.5	-195.5	-424.9	-577.5	-595.2	-718.4	-847.5	-764.4
CASE 6/A	-107.0	-87.6	-118.1	-18.8	-14.3	-54.7	30.0	35.0	5.0
CASE B	39.8	81.5	42.1	93.2	97.3	151.5	179.9	191.0	190.0
CASE C	15.4	54.3	31.5	52.6	95.6	62.1	93.0	138.0	117.0
CASE D	25.4	63.5	47.4	71.5	116.1	80.1	128.2	163.0	140.0
CASE E	89.2	92.8	73.8	61.4	87.1	49.3	62.0	113.0	65.0
CASE F	188.8	193.0	238.7	283.7	319.5	337.2	347.2	402.7	336.7
CASE G	290.5	398.7	363.4	453.7	573.8	540.3	764.7	834.0	662.3

Table 13
Percent Deviation in Energy Savings BLAST versus Micro
100*(Micro-BLAST)/BLAST

	PHOENIX			COLUMBIA			BISMARCK		
	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP	BLAST	OPCOST	SASEAP
CASE 2		77.4%	-65.5%		304.3%	-169.6%		84.4%	-99.6%
CASE 3		21.7%	39.3%		-33.3%	86.8%		6.9%	19.9%
CASE 4		46.9%	53.3%		34.3%	44.0%		60.5%	33.3%
CASE 5		55.0%	-10.7%		35.9%	40.1%		18.0%	6.4%
CASE 6/A		-18.1%	10.4%		-23.9%	191.0%		16.7%	-83.3%
CASE B		104.8%	5.8%		4.4%	62.6%		6.2%	5.6%
CASE C		252.6%	104.5%		81.7%	18.1%		48.4%	25.8%
CASE D		150.0%	86.6%		62.4%	12.0%		27.1%	9.2%
CASE E		4.0%	-17.3%		41.9%	-19.7%		82.3%	4.8%
CASE F		2.2%	26.4%		12.6%	18.9%		16.0%	-3.0%
CASE G		37.2%	25.1%		26.5%	19.1%		9.1%	-13.4%



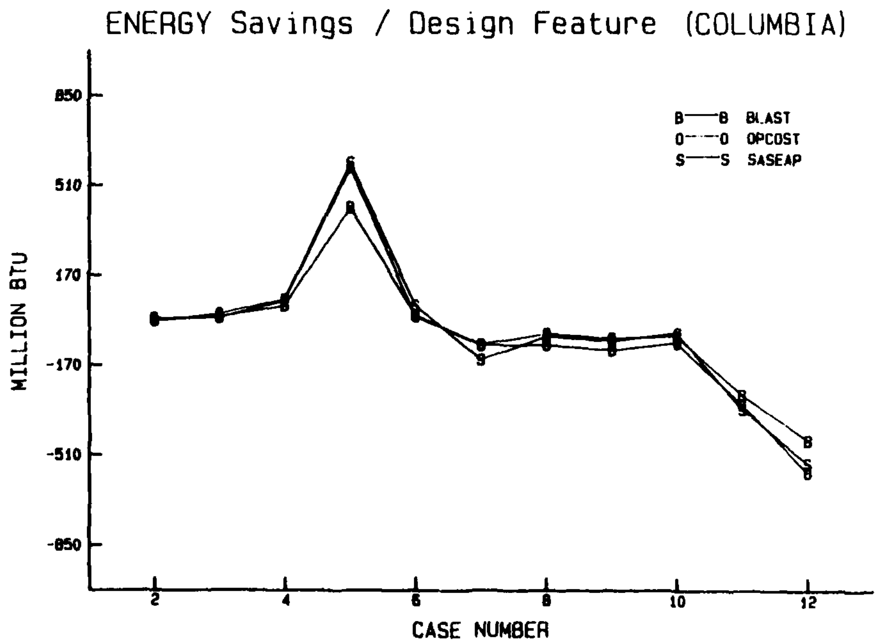
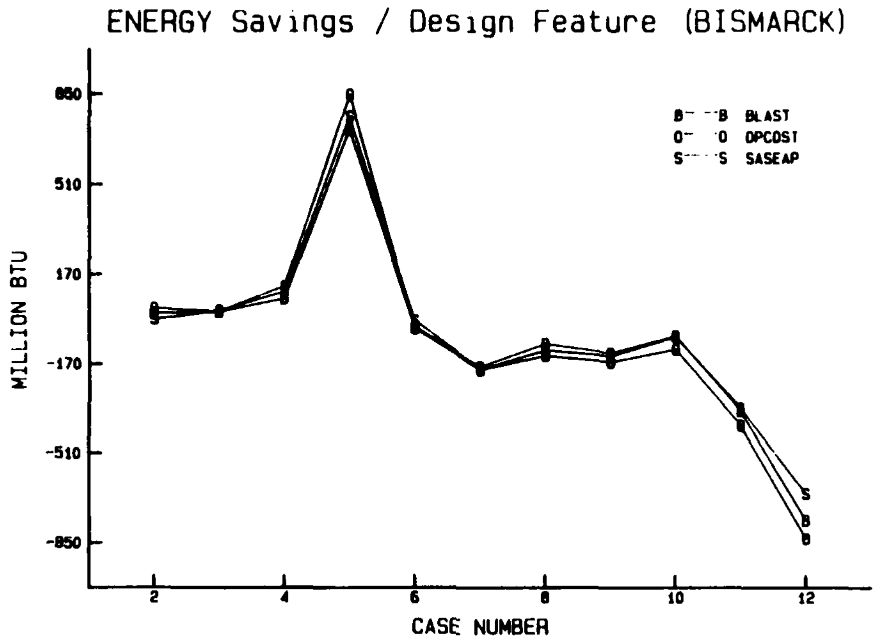


Figure 10. Impact of design features on energy consumption.



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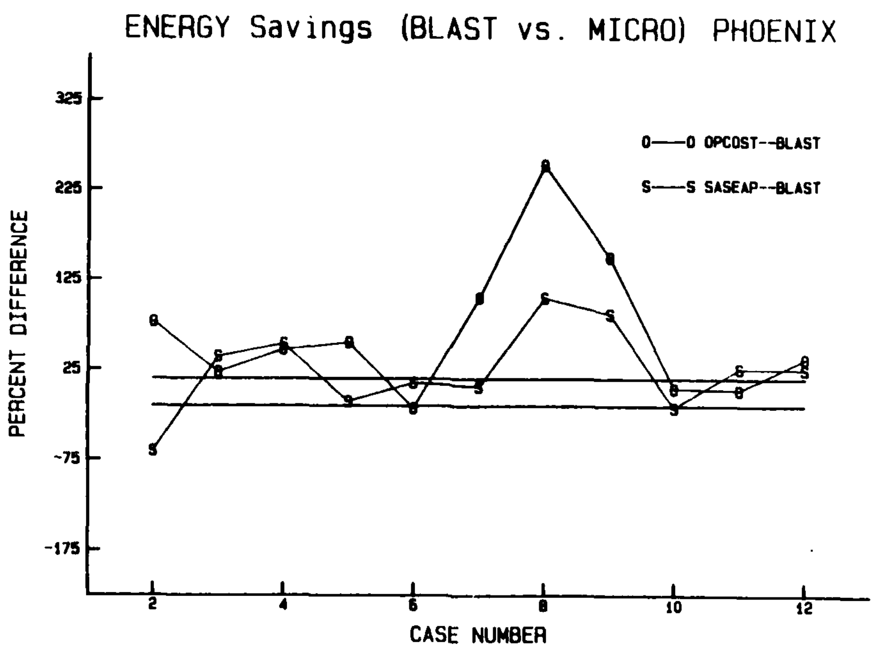
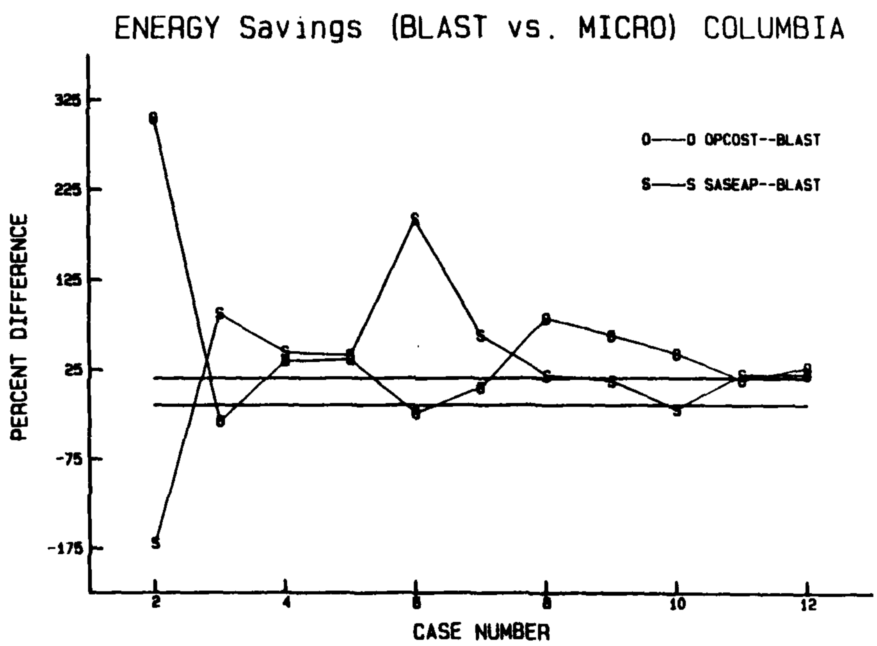
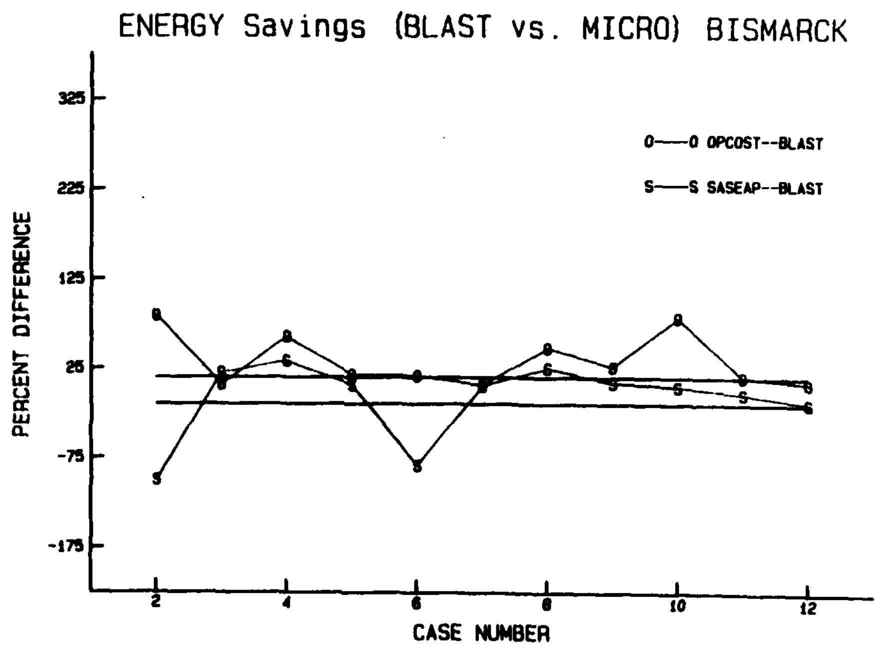


Figure 11. Deviations between BLAST-computed and micro-computed energy savings.





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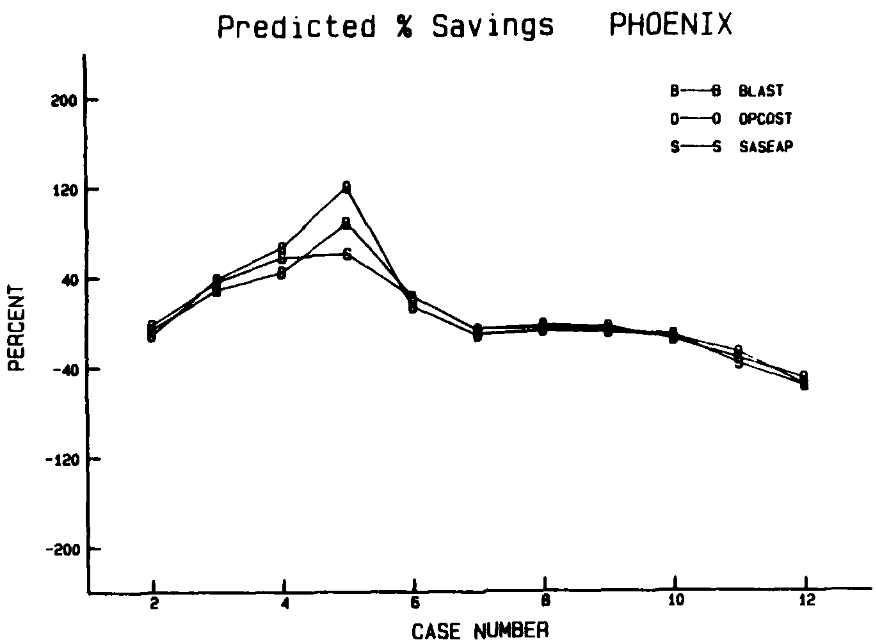

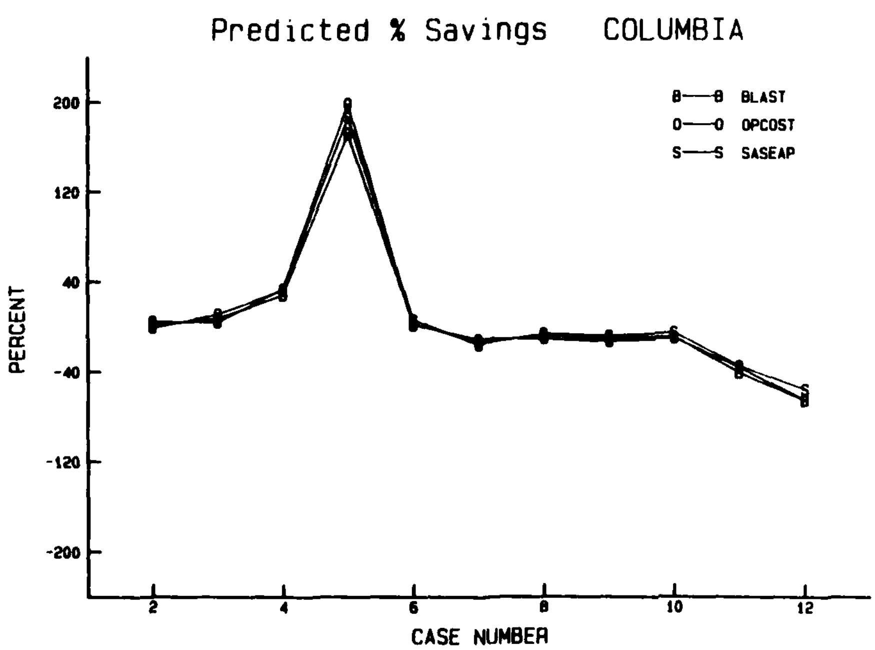

Figure 12. Percent savings of design options.

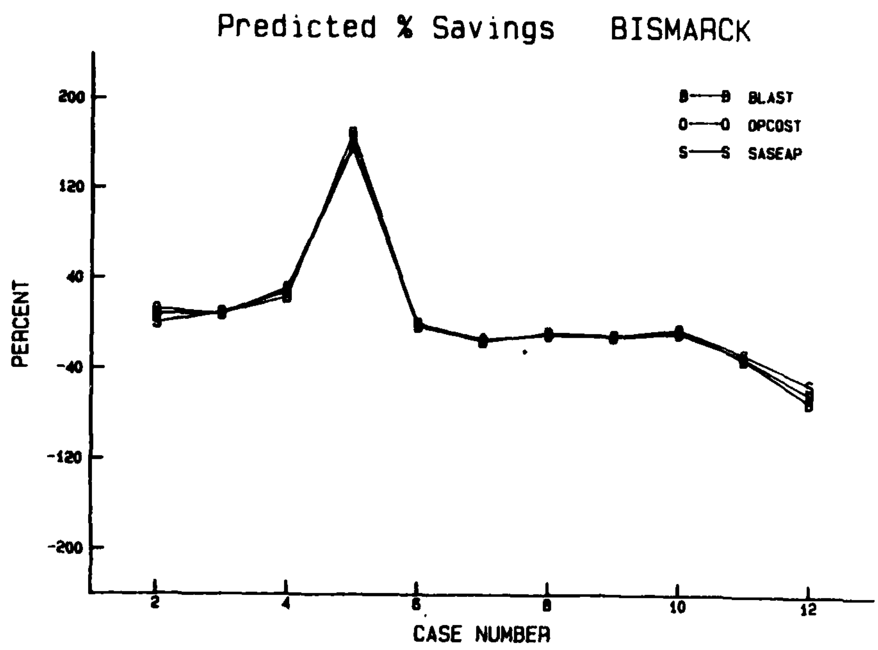

Figure 12. (Cont'd).

5 CONCLUSIONS AND RECOMMENDATIONS

The microcomputer energy analysis programs based on the bin method have not proven accurate or flexible enough for wide-scale application in the Army's Military Construction Program. The evaluation showed that there were major deviations between the data generated by the micro programs and by BLAST—sometimes as high as 300 percent, and with energy errors exceeding 40 percent. Thus, the micro programs are not accurate enough for certifying energy budget compliance in accordance with ETL 1110-3-309 or for studying the life-cycle costs of design options as prescribed in ETL 1110-3-332. The microcomputer energy analysis programs seem to have their best application in concept studies where the important criterion is ranking design and retrofit options. Both micro programs were found to have entries that were not well-defined. These were intermediate temperatures for analysis, color correction factor, building weight, and wall and roof color.

This study evaluated only two of the available micro energy analysis programs. However, the results vary

enough from those obtained with the detailed energy analysis program to indicate that before any micro program is used, it should be evaluated for its ability to make the energy calculations needed by the Army.

Microcomputer energy analysis programs based on the bin method should not be used for certifying budget compliance, for life-cycle cost studies, or for justifying energy conservation retrofit projects.

The Army should develop a procedure for evaluating new energy analysis programs as they become available.

Metric Conversion Factors

°F	=	$(°F \times \frac{9}{5}) + 32 = °C$
1 sq ft	=	.092 m^2
1 in.	=	25.4 mm
1 cu ft/min	=	0.028 m^3/min

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